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M I N U T E S A N D P R O C E E D I N G S

of the twenty-third meeting of the

ARMED FORCES - NRC VISION COMMITTEE

March 4-5, 1949

National Academy of Sciences
Washington, D. C.

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Minutes of the Twenty-third Meeting

March 4-5, 1949

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Saturday, March 5, 1949 Page No.

12. Dr. John Volkmann presented a paper entitled "The Discrimination of Visual Number" - 85

13. Dr. W. J. Crozier presented a paper entitled "On the Seeing-Frequency Function" - 89

14. Dr. W. S. Verplanck, and Mr. C. K. Bishop, presented a report entitled "Further Results, Field Tests of Optical Instruments." - - - - - 135

15. Dr. E. O. Hulburt, Chairman of the Subcommittee on Visibility and Atmospheric Optics, reported that the Subcommittee held a meeting on March 3, 1949. Full reports of the projects conducted by Dr. Howard S. Coleman, Dr. S. Q. Duntley, and Dr. H. Richard Blackwell were presented before the Subcommittee, and abbreviated forms of the reports were presented before the full Vision Committee, as indicated below. Discussion of the reports which occurred at the Subcommittee session follow the text of the reports, as do discussions held at the Vision Committee meeting.

16. Dr. H. S. Coleman presented a paper entitled "Atmospheric Attenuation of Brightness Contrast Along a Horizontal Path For the Visible Range of the Spectrum" - 101

17. Dr. H. R. Blackwell presented a paper entitled "Report of Progress of the Roscommon Visibility Tests, June, 1947 to December, 1948" - 107

18. Dr. S. Q. Duntley presented a paper entitled "Interim Report on Exploratory Studies of the Physical Factors Which Influence the Visibility of Submerged Objects" - - - - - - - - - - - - - - - - 123

19. Dr. Hulburt, Chairman of the Subcommittee on Visibility and Atmospheric Optics, presented two resolutions for the consideration of the Vision Committee, concerning continuation of Dr. Duntley's and Dr. Coleman's projects. The resolutions were approved by the Vision Committee in the following form:

RESOLUTION: The Vision Committee expresses its confidence in the studies of optical problems of water surface, being conducted by Professor S. Q. Duntley at Massachusetts Institute of Technology, and expresses its hope that the work can be carried to completion.

RESOLUTION: The Vision Committee expresses its confidence in the studies of atmospheric attentuation being undertaken by Professor Howard S. Coleman, at the University of Texas, and expresses its hope that the work can be carried to completion. In view of the importance of the additional information, the Vision Committee

recommends to the Office of Naval Research that consideration be given to broadening the scope of the studies in atmospheric optics, being conducted by Professor Coleman to include point sources of light and visual range observations at night, associated with a study of the sizes and concentration of suspensoids and precipitation involved.

Dr. Hulburt expressed the appreciation of the Subcommittee for Dr. Blackwell's work on the Roscommon visibility tests. He stated that it was his understanding that Dr. Blackwell had virtually completed the study, therefore, a recommendation for continuance of the project was not necessary.

20. Dr. Jesse Orlansky presented a paper entitled "Estimates of Visibility from High Altitude Aircraft", a summary of which is presented in the Proceedings - - - - - - - - - - - - - - - - - - - 127

21. Mr. W. E. K. Middleton expressed the need for data to be collected concerning the range of conditions of adaptation and background luminance (brightness) which prevails at airports where meteorological observations are made. This information is of particular interest to the Commission on Atmospheric Optics, of the International Meteorological Organization, of which Mr. Middleton is president. After discussion, the Vision Committee approved the following recommendation for transmittal to the U. S. Air Forces:

RECOMMENDED THAT: the Vision Committee request the U. S. Air Force to conduct a survey to determine the range of conditions of adaptation and background luminance actually prevailing at airports when meteorological observers are making observations of visibility at night.

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ABSTRACTS - 151

Report of the
Subcommittee on Illumination
Armed Forces-NRC Vision Committee
March 4, 1949

The Subcommittee on Illumination was called upon by the chairman of the Vision Committee to represent the Vision Committee in a joint meeting between the Subcommittee on Illumination and the IES-APHA joint committee on February 19, 1949. The Subcommittee on Illumination met on February 18 to prepare for this conference. Also present at the conference on February 19 were Dr. Scobee, Chairman of the Vision Committee, and the members of the Subcommittee on Visual Standards. The purpose of this conference was to get behind the scenes of the Illuminating Engineering Society to become familiar with the bases that are being used in formulating standards for illumination and to determine what might be done by way of research and cooperative effort in the future for providing better lighting and determining the relationship of poor lighting to visual discomfort and inefficiency and the impairment of eyesight and health.

A full report of this meeting can be made available to those who may be interested.

The chairman of the Subcommittee will present at the Vision Committee meeting in Washington on March 4, 1949, a paper on the subject "Use of Threshold and Performance Data for Recommending Quantity of Illumination", which is concerned with one of the major topics considered at the conference referred to. One of the members of the committee has been assigned the task of preparing a second report on the relation of brightness level and distribution of brightness in the visual field to pupil size and changes in pupil size associated with eye movements and nonuniform distributions, and the relation of size of pupil and change in pupil size to visual discomfort. It is hoped by a series of such reports to bring to the attention of the Vision Committee the principles underlying the formulation of standards in illumination and the need for further research in this area.

It may be worthwhile also to call attention to the existence of the I.E.S. Coordinating Committee for Defense, which is set up for the purpose of helping make available to the various government agencies concerned with national security the services of the I.E.S. This group is prepared to offer assistance in solving practical problems of illumination, and any unit of the Armed Forces which wants to avail itself of such service can do so through the Vision Committee or directly through this Coordinating Committee for Defense. The Chairman of the Subcommittee on Illumination is a member of that committee and provides liaison between that committee and the Vision Committee.

Glenn A. Fry, Chairman

H. Richard Blackwell
Dean K. Farnsworth
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DISCUSSION:

Dr. Fry commented that he would appreciate the opinion of the Vision Committee as to the role the Subcommittee on Illumination should play. At one extreme, the Subcommittee might simply provide liaison with the Illuminating Engineering Society. At the other extreme, the Subcommittee might attempt to recommend standards for illumination and produce other technical information concerned with illumination problems.

Dr. Fry pointed out that the two extremes were not too far apart, since any illumination recommendations made by the Subcommittee should be coordinated with similar recommendations emanating from the Illuminating Engineering Society. Dr. Fry also called attention to the fact that the problem of standardization of illumination ran through other Subcommittees of the Vision Committee, as for example, the Subcommittee on Visual Standards which had standardized on an illumination level to be used in the testing of visual acuity.

Dr. Fry suggested that the Subcommittee should attempt to maintain liaison with the I.E.S. and with other Subcommittees, and consider its task to be that of informing the main Committee of any progress made in the specification of illumination standards.

Mr. Crouch expressed his belief that the Illuminating Engineering Society would welcome any activities of the Subcommittee which would assist the I.E.S. in its over-all task of determining procedures or standards to be used in specifying illumination.

Dr. Scobee summarized the discussion by defining the Subcommittee's function as one of maintining liaison with I.E.S., keeping the Vision Committee informed of any progress in standardization of illumination, and disseminating information to subcommittees such as the Visual Standards Subcommittee.

USE OF THRESHOLD AND PERFORMANCE DATA FOR RECOMMENDING QUANTITY OF ILLUMINATION

Report No. 1
Subcommittee on Illumination

Glenn A. Fry

Introduction

The field of view at any moment or during each pause of fixation can be divided into a small central region 3° in diameter and a peripheral region.

Many visual tasks require peripheral as well as central vision, and in many situations peripheral vision is used to the almost total exclusion of central vision. However, the tasks for which the illuminating engineer has to provide illumination usually require major emphasis on central vision. That is to say, all of the things that have to be seen at a given moment or during a given pause of fixation are included within a small central field. A succession of fixations may be required to perform the task, but at each fixational pause the central field is the thing of importance.

The engineer must take into consideration the changes in the position of the observer with respect to the space in which he works, and the changes in the direction of fixation, and then he sets out to provide adequate illumination for each position of the observer's eye and each direction of fixation.

He aims first of all to make visible all of the lines, points, and borders within the central field which have to be seen. In many instances it is not at all easy to analyze this complex of elements and proceed in any simple straightforward manner to determine what quantity of illumination ought to be recommended.

It is possible, however, to carry out controlled experiments with a simple pattern or test object that has a configuration, size, and contrast that can be specified, and also has a background which is uniform and which extends uninterruptedly into the periphery of the field of view and includes the whole field of vision. Basic data obtained with these simple patterns in a laboratory can be used in formulating general principles which may be applied both to the simple and the more complex patterns.

The illuminating engineer must also be concerned about the effect of the distribution of brightness in the peripheral field upon the visibility of the lines, points, and borders that fall within the central portion of the field. This aspect of the problem can be also investigated through controlled experiments.

The engineer makes a distinction between quantity and quality of lighting. Quantity of lighting refers to the intensity of illumination falling on the objects in the central portion of the field of view, and quality of lighting refers to variations in the distribution of brightness in different parts of the field of view.

The engineer is interested not only in the effect of quantity and quality of light on the visibility of lines, points, and borders, but also the effect

on the speed and accuracy of the performance of the task.

As will be pointed out later, there is a very basic relation between visibility and performance in certain types of tasks. However, in more complicated cases, other factors, such as perception of form, segregation of figures from backgrounds, perception of position and movement, have to be considered as well as sheer visibility.

The illuminating engineer must also be concerned with the comfort and efficiency of the worker, and the possibility of permanent impairment of his vision and health through poor lighting.

If it is not obvious already, it may be well to point out that this discussion is going to be limited to stimulus patterns having one chromaticity, namely white, and which can be described in terms of the brightness distributions within the visual field.

As implied in the title, the main objective of this paper is to discuss the use of threshold and performance data as a basis for prescribing the quantity of the illumination for a given task.

It is admitted at the outset that a determination of the quantity of light needed on the object or objects that have to be seen with foveal vision is merely a starting point.

Even in the case of a printed page, the engineer has to pay attention to avoiding reflected glare as well as providing a given quantity of illumination. In the case of three dimensional objects, the control of high lights and shadows is extremely important.

He has to consider not only the effect of the absolute brightness level at the center of the field, but also the relative distribution of brightness in the entire field and its effect on pupil size, veiling haze, comfort, and changing adaptation states associated with eye movements.

He has to start compromising when the worker has to put his head in many different positions and point his eyes in many different directions.

He has to make visible all objects that can prove a hazard to the safety of the worker, and he must illuminate the worker's path as he moves into and out of the room and from one part of the room to another.

He has to compromise further when two or more workers perform different tasks in the same room at the same time.

He has to compromise still further when he considers the comfort of the worker and the possible permanent impairment of his health and eyesight.

Even though the determination of quantity is admitted to be only a starting point, and even though one can belittle its importance in comparison with the other things that an engineer has to consider, we cannot dispense with this step altogether, and of necessity therefore, we must be concerned with the formulation of standards and procedures to negotiate it.

Performance data provide the basic criterion for selecting a quantity of illumination, but because of the relation that exists between threshold data and performance data, threshold data can be used for predicting performance and hence can be used indirectly for determining quantity.

The first point to consider, therefore, is the basic relation between threshold data and performance data. This relation becomes apparent first of all through the consideration of the effect of stimulus duration on visibility. In the second place it becomes apparent through the consideration of frequency of seeing data.

Effect of Stimulus Duration on Visibility

Duration is important from several points of view. In the first place, a given stimulus pattern may be only momentarily or intermittently exposed, and the duration of a single exposure will affect the visibility. Special cases of intermittent exposure are intermittent or oscillating motion. Furthermore, smooth motion of a small object results in momentary exposure for a given element on the retina provided the eye is stationary or is not following the object perfectly. When the observer moves his eyes from one part of the field of view to another to see successively different stimulus patterns which have to be observed critically in order to perform the task, each fixational pause constitutes a unique exposure. In reading, for example, the eye undergoes a succession of movements with fixational pauses between, which have a minimum duration in the neighborhood of $150\ \sigma$.[1]

In order to insure complete visibility, the illuminating engineer and his colleagues who design the stimulus pattern must aim at insuring complete visibility for the shortest possible exposures and pauses of fixation.

In general there will not be large variations of brightness in the field of view, and hence as the eye moves from point to point, a fairly constant state of adaptation will be maintained. Consequently, when the effect of duration on visibility is investigated, it is desirable for the presentation of the test object and its background to be preceded and followed by a uniform field of brightness equivalent to the background of the test object.

Ferree and Rand[2] have accumulated data of this sort for the Landolt ring using various sizes, contrasts, and brightness levels. Most of their data have been presented in the form of graphs relating speed of vision to level of illumination. By interpolation, certain of these data have been converted and replotted in Fig. 1 in the form of graphs relating contrast to the brightness of the background. The separate curves on each graph represent various durations of exposure.

Increasing the duration permits the observer to see at lower and lower brightness levels. The effect of increasing the duration of the exposure extends over quite a large range. Actually Ferree and Rand made no attempt to determine the upper limit of this effect, but presumably this is represented by a curve for continuous exposure. The dotted curves in Fig. 1 for continuous exposure are based on data obtained by interpolation from the data of Connor and Ganoung[3] for continuous exposure for the Landolt ring.

Cobb[4] designed an experiment which permitted the observer to fixate the center of a pre-exposure confusion pattern like Fig 2A for a short period, and then this was exchanged suddenly for the parallel bar test object, and finally a switch was made to the post-exposure confusion pattern in Fig. 2C. Cobb compared results obtained from this arrangement with those obtained with uniform pre- and post-exposure fields.

These two types of data are compared in Fig. 3, which apply to a parallel bar test object with a 1.82' space between the bars and a contrast of about 0.96. The subjects were required to estimate whether the bars were horizontal or vertical, and a criterion of 75% correct guesses was used in defining the threshold. As indicated in the graph, the pre- and post-confusion patterns increased the length of time required to perceive the orientation of the bars. Cobb's experiment is particularly applicable to the case of reading where the material confronting the eye in one fixational pause constitutes a confusion pattern for the material presented in the previous and in the following fixational pauses.

Since fixational pauses such as occur in reading definitely fall within the range of durations in which visibility is affected, it may be concluded that the requirements for visibility are likely to impose limitations upon the speed and accuracy of performing visual tasks.

Unfortunately, data of the type obtained by Ferree and Rand do not extend to very low levels of contrast and consequently we do not have available adequate information relative to the shape of the complete curves relating contrast-thresholds and brightness for different durations of exposure.

Keller[5] has used a stimulus pattern similar to that shown in Fig. 2 to determine the minimum perceptible difference in brightness ΔB for Various brightness levels and durations of exposure. For durations of the order of 200 milliseconds, Keller found a curve with an upturn at high brightness levels (Fig.5). This indicates that the best performance is obtained with a medium brightness, and that it is possible to make the brightness too high. This phenomenon, as Keller points out, is related to the problem of action time.

It remains to be seen whether this type of thing holds for the curve representing the relation between contrast thresholds and brightness for test objects such as the broken circle, which are dark on a bright background and momentarily exposed.

Frequency of Seeing Data

In the region of the threshold of visibility, the line, point, or border which is near its threshold is not seen every time it is presented, and hence one can use the frequency of seeing, or the ratio of the number of times seen, to the number of times presented as a measure of degree of visibility. As a matter of fact, one can draw on a plot of log contrast against log brightness a series of curves showing for a given duration of exposure the various frequencies of seeing.

Complete sets of data of this type are not available, but it is necessary to consider this aspect of the data in trying to relate visibility data to performance data which involves speed and accuracy of seeing.

Basic Visibility Data for Illuminating Engineers

Illuminating engineers must provide themselves with certain basic data relative to visibility, in order to be assured that the levels of illumination prescribed insure complete visibility. These data should apply to the situation in which the entire surround is uniformly bright and has the same brightness as the immediate background of the standard pattern. The data should also represent data for distance vision for the standard observer of about the age of 20 with relaxed accommodation, and either with the natural pupil or an artificial pupil of specified size.

A number of graphs are needed. Each graph should represent a plot of log contrast against log brightness with a series of curves representing different durations of exposure. One each of such graphs is needed for a limited number of standard stimulus patterns of different overall size and configuration. The graphs in Fig. 1 are examples of the type of graphs needed.

The basic variable which the engineer can control is the level of illumination, and since the reflection factor of the object illuminated is constant the illumination and the reflection factor determine the brightness. In the case of three dimensional objects, the engineer can to a limited extent control the contrast by manipulating the position of the light sources, but in many instances, exemplified by black letters printed on white paper, it is not possible to influence the contrast by manipulating the illumination falling on the printed page except by controlling "reflected glare". A graph like that in Fig. 1 gives the information that an engineer needs relative to visibility and the variables, brightness and contrast, which he can manipulate.

The advantage of plotting log contrast against log brightness is that this type of graph is useful in evaluating the use of a visibility meter for prescribing levels of illumination.

The advantage of plotting data for different durations of exposure on the same graph is that this makes it possible to correlate basic visibility data with the speed and accuracy of performing various visual tasks.

Once the effect of duration of exposure is completely understood, it may not be necessary for engineering purposes to include separate curves for different durations of exposure. A single curve for continuous exposure should suffice. If a single curve will suffice for a stimulus pattern of a given configuration and overall size, a number of continuous exposure curves can be included on the same graph representing various sizes as shown in Figs. 6 to 9. This reduces by a considerable factor the total number of graphs that have to be kept on file.

It is to be noted that Fig. 9 applies to the case of a stimulus pattern brighter than the background. Contrast in this case is defined as the ratio of the brightness difference between the test object and its background and the brightness of the background. This method of defining contrast makes the data more usable when attempting to relate them to the use of a visibility meter.

A great deal of data have been accumulated for the visibility of bright objects observed against backgrounds of zero or negligible brightness. Although this sort of data is useful for other situations, it is not applicable to problems

of the illuminating engineer, because he is basically concerned with illuminating bright or dark objects on backgrounds which have finite reflection factors, the lowest reflection factor being of the order of 0.04.

In the case of a bipartite test object of large diameter, there appears to be no satisfactory basis for deciding whether to express the contrast in terms of a brightness level equal to the brighter or to the darker of the two halves of the field. For the purpose of correlating it with data obtained with the visibility meter, it would probably be better to use an average of the two brightness levels.

A different type of problem occurs in the case of a grating which covers a large portion of the visual field. Because of eye movements, all parts of the retina are likely to get stimulated equally, and hence the general adaptation level will probably depend upon the average brightness of the field.

Weston's Performance Data

Weston 8, 9, 10 has published performance data which are most useful in attempting to understand the relationship between performance and visibility. Each subject in the experiment was presented with a work sheet similar to the one shown in Fig. 10. The subject was instructed to cancel out the rings having the opening point in a given direction. The total number of rings cancelled was divided into the time used. This determined the time required for each ring cancelled, and from this was deducted the average time required to cancel a ring when no attention was paid to its orientation. This was determined in an independent investigation in which the rings to be cancelled were colored red for easy identification. The reciprocal of the net time gives the speed of perceiving the orientation of the test object. The speed score was then multiplied by the accuracy score, which was the ratio of the number of rings correctly cancelled and the total number of rings which might have been cancelled in the time used. Separate sheets with rings of different size (S) and different degrees of contrast (C) were employed. Size (S) refers to the width of the gap in minutes. The level of illumination (E) was also varied. From the raw data for a given size and contrast, it was possible to determine the maximum performance which could be produced by increasing the level of illumination. The ratio of the score for a given background brightness (B) to the maximum score was taken as a measure of relative performance.

In one investigation Weston kept the reflection factor of the background constant at .90 and varied C, S and E.

For various values of C (0.97, 0.56, 0.39 and 0.28), Weston plotted the relative performance for various values of E (0.5, 2, 8, 32, 128 and 512 foot-candles), and interpolated to determine the value of E corresponding to the 90% performance level. This procedure was repeated for various values of S (1.5', 3' and 4.5').

Within close approximation the following equation represents the relation between B, S and C for the 90% performance level.

$$B = \frac{55.68}{S^3 C} \qquad (1)$$

Figs. 11 and 12 show the relationship of Weston's equation for the 90% level of performance to the Connor-Ganoung data for the threshold of visibility.

Standards for Recommending Quantity of Illumination

The British Illuminating Engineering Society is using Weston's equation for defining recommended levels of illumination. The use of this equation involves, of course, a knowledge of the contrast, the size of the critical detail which has to be seen, and the reflection factor of the background.

The solid line in Fig. 11, which is a plot of Weston's equation, represents in terms of British standards the dividing line between recommended and non-recommended levels of illumination. Plotted on the graph are the threshold data obtained by Connor and Ganoung. The data for contrast levels above 0.30 can be fitted reasonably well by the straight dotted line. For practical purposes it may be just as satisfactory to substitute for the Weston line, the dash-dot line which is parallel to the dotted line and displaced two log units to the right. The advantage in using this line as a standard line for prescribing illumination is that it corresponds to a suprathreshold level of visibility as measured with the Luckiesh-Moss Visibility Meter.

A new graph has to be constructed each time a new test object of a different size or configuration is used, but it will simplify matters if it can be assumed in each case that the standard line is parallel to and lies two log units to the right of the straight dotted line representing the threshold for contrast values ranging from 0.20 to 1.00 contrast. It should be noted in this connection that in Fig. 12 Weston's equation is nearly parallel to the straight dotted line fitting Connor and Ganoung's data for the threshold and approximately two log units to the right. This means that for Landolt rings of high contrast, the Weston recommended level falls approximately two log units above the threshold level for all sizes.

Inasmuch as the data for the whole range of contrast values from the highest to the lowest cannot be fitted by a straight line as is illustrated in Fig. 11, it is not possible to use the Luckiesh-Moss Visibility Meter for prescribing illumination at lower levels of contrast. Also since Weston's equation is based on data which are limited to contrast values between 0.97 and 0.28, there is no justification in the actual data for using Weston's equation to prescribe illumination at low levels of contrast.

Let us consider at this point the implications of extending the dash-dot line in Fig. 11 to lower levels of contrast and using this single line as the dividing line between recommended and non-recommended levels of illumination for all levels of contrast.

Moon and Spencer [11] have used the concept of delos to deal with the problem of relative visibility of objects at the threshold level. According to this concept, the contrast delos of a test object is equal to the ratio of the contrast threshold that would be obtained if the illumination were increased indefinitely to the contrast threshold at a given level of illumination. If the curve representing threshold data is defined by the following equation,[26]

$$C = \frac{C_\infty}{B}\left[\left(\frac{C_1}{C_\infty}\right)^{\frac{1}{2}} + B^{\frac{1}{2}} - 1\right]^2, \qquad (2)$$

where C_1 and C_∞ are the values of C at values of 1 and ∞ for B, and if the straight line approximation for the data of high levels of contrast is defined by the following equation,

$$\log C = .59 \left[\log B_1 - \log B \right] , \qquad (3)$$

where B_1 is the brightness level of the background at which the threshold level of contrast is equal to one, the proposed standard dash-dot line which lies two log units to the right of the dotted threshold line would intersect the dashed threshold curve at a brightness level of 63 footlamberts. This corresponds to a delos of .95. Spencer[12] has recommended that a delos of .80 is the minimum, .85 is good, and .90 is excellent. The result obtained, therefore, by extending the dash-dot line to the threshold level is in reasonable agreement with the recommendation made by Spencer for the threshold level of visibility. If the complete recommendation of Spencer were followed, the dividing line between recommended and non-recommended levels of illumination would be a vertical line on the graph. In view of Weston's data and in view of the visibility data for short exposures, it is almost certain that the line dividing recommended and non-recommended levels of illumination ought to have a finite slope. This constitutes the justification for adopting the sloping dash-dot line in Fig. 31 in preference to a vertical line.

For many types of test objects it is found that the curve relating threshold contrast to brightness shows an upturn at high brightness levels. This appears, for example, in the data of Koenig and Brodhun[13] for a bipartite test object on a dark field (See Fig. 13). The dividing line was horizontal and divided the pattern into two parts each 3° wide and 4-1/2° long. If this is dependent on the interference of the outside border of the pattern upon the visibility of the dividing line, the effect should disappear, as might be inferred from the experiments of Fry and Bartley[15], if the brightness of the surround were made nearly equal to that of the test object. Fig. 14 shows a set of data by Steinhardt[16] for bipartite test objects with backgrounds kept at various fractional values of the brightness of the test object. Steinhardt failed to obtain an upturn even with a dark background, but the data show trend in this direction.

One might also expect the upturn to decrease by increasing the size of the field. Fig. 15 shows the actual effects obtained. Although increasing the size lowers the threshold, the upturn actually appears only with the larger fields. Hecht[14] has suggested that this effect is due to incomplete adaptation to the various brightness levels.

Using a disk-annulus type test object like that shown in Fig. 16, Fry has obtained a curve with an upturn as shown in Fig. 17 when the distance between the borders was 0.68°, but this was missing when this distance was increased to 2.28°. This indicates that the upturn in the one curve may be due to the interference of the outside border of the annulus on the visibility of the border of the disk.

Wilcox[17], Fry and Cobb[18], and Byram[19] have shown an upturn in curves for resolution thresholds at various brightness levels obtained with bright parallel bar test objects on a dark background. The data obtained by Fry and Cobb are shown in Fig. 19. This data provides evidence that this upturn is dependent on the influence of the outside borders of the bars on the visibility of the space between the bars.

It has already been pointed out that upturns may also be related to duration of exposure.

Regardless of what causes the upturns, they are important for illumination standards in that they pose a fundamental objection to the theory that there is no limit to the improvement in visibility which accrues from increasing the level of illumination. At least for certain types of stimulus patterns the brightness can be too high.

A Basic Limitation of Weston's Data

It should be further pointed out that Weston's data involves a very limited number of visual skills. Such skills as detecting brightness and color differences for objects which are completely separated from each other, stereopsis, judgment of relative size, distance, direction, and movement are all skills affected by quantity and quality of illumination.

It may well be that a recommendation of quantity and quality based on basic visibility data and performance data of the Weston type will be also most favorable for the use of these other visual skills, but this has to be proved.

It may actually turn out to be necessary to analyze the visual skills required for each task before a recommendation can be made concerning quantity and quality of illumination.

References

1. E.A. Taylor, Controlled Reading, p. 126 (1937). See also P.W. Cobb and F.K. Moss, J. Exp. Psych., 9, 359-367 (1926).
2. C.E. Ferree and G. Rand, J. Exp. Psych., 12, October (1929).
3. J.P. Connor and R.E. Ganoung, J. Opt. Soc. Am., 25, 287-294 (1935).
4. P.W. Cobb, J. Exp. Psych., 8, 77-108 (1925).
5. M. Keller, J. Exp. Psych., 28, 407-418 (1941).
6. P.W. Cobb and F.K. Moss, J. Franklin Institute, 205, 831-847 (1928).
7. H.R. Blackwell, J. Opt. Soc. Am., 36, 624-643 (1946).
8. H.C. Weston, The Relation between Illumination and Industrial Efficiency. 1. The Effect of Size of Work (Joint Report of the Industrial Health Research Board and the Illumination Research Committee H.M.S.O. (1935).
9. H.C. Weston, Trans. I.E.S. (London) 3, 17-39 (1943).
10. H.C. Weston, The Relation between Illumination and Visual Efficiency - The Effect of Brightness Contrast, Report #87, Industrial Health Research Board, Medical Research Council (1945).
11. P. Moon and D.E. Spencer, J. Opt. Soc. Am., 34, 605-617 (1944).

[redacted]

12. D.E. Spencer, Preliminary Report #5 of the Committee on Standards of Quality and Quantity of Interior Illumination of the Illuminating Engineering Society (Mimeographed). See also P. Moon and D.E. Spencer, J. Opt. Soc. Am., 34, 605-617 (1944).

13. A. Koenig and E. Brodhun, Sitzungsber Akad. Wissensch., Berlin, 917-931 (1888).

14. S. Hecht, J. Gen. Physiol., 18, 767-789 (1934-35).

15. G.A. Fry and S.H. Bartley, Amer. J. Physiol., 112, 414-421 (1935).

16. J. Steinhardt, J. Gen. Physiol., 20, 185-209 (1936-37).

17. W.W. Wilcox, J. Gen. Psych., 15, 405-435 (1936).

18. G.A. Fry and P.W. Cobb, Am. J. Psych., 49, 76-81 (1937).

19. G.M. Byram, J. Opt. Soc. Am., 34, 718-743 (1944).

Figure Legends

Fig. 1. Effect of duration of exposure and size of the gap in a Landolt ring on the contrast threshold at different intensity levels. Data for indefinitely prolonged exposure from Connor and Ganoung[3] (see Fig. 6). Data for short exposures from Ferree and Rand[2], who used monocular observation without an artificial pupil.

Fig. 2. Cobb's stimulus pattern (B) and his confusion patterns (A and C) for pre- and post-exposure.

Fig. 3. Cobb's data on the effect of pre- and post-confusion patterns on the duration of exposure required for visibility at different brightness levels. Stimulus patterns shown in Fig. 2. Binocular observation without artificial pupils.

Fig. 4. Keller's stimulus pattern.

Fig. 5. Keller's data for 0.2 sec. exposure for two subjects. Monocular observation with an artificial pupil 3 mm. in diameter. ΔB represents a just noticeable brightness difference between the two half-disks.

Fig. 6. Threshold data for Landolt rings with an exposure of 3 sec. or more (Connor-Ganoung[3]). Binocular observation with natural pupils.

Fig. 7. Threshold data for parallel bar test object with an exposure of 0.17 sec. (Cobb and Moss[6]). The data have been fitted arbitrarily with curves which conform to Equation (2).

Fig. 8. Blackwell's[7] data for dark disks on an extended bright background. The curves represent data for disks of different diameter. The eyes were adapted to the background brightness. A free scanning type of fixation was used. Binocular observation with natural pupils.

Fig. 9. Blackwell's[7] data for bright disks on an extended darker background.

[redacted]

DISCUSSION:

Mr. Crouch described the methods by which the I.E.S. approaches problems of standardizing quantity of illumination. He listed two approaches: (1) an approach based upon visual data of the sort described by Dr. Fry; (2) the empirical approach made by engineers in the field. The engineers, of course, attempt to be fully cognizant of the laboratory kind of data. In recommending quantity of illumination levels for specific situations, the engineers normally study a particular problem for periods from six months to a year, often resorting to special laboratory examinations of certain aspects of the problem.

Mr. Crouch made it clear that the I.E.S. wished to bring together the two approaches and that in fact recommendations arrived at by the two approaches have not in the past been discordant. Mr. Crouch described briefly the various technical committees of the I.E.S. which have been concerned in the past with standardization of lighting in such situations as school rooms, highways, and industrial plants.

Mr. Crouch mentioned the fact that Weston found the specification of illumination levels to depend somewhat upon the age group used. He found that there was a 5% decrease in visual performance over a five year age span for young workers, but that the decrease rose to 7% for five increase in age at middle age. The net result of this finding is that higher levels of illumination improve visual performance more for "oldster" than for "youngster".

Dr. Sloan commented on the drop in acuity which is reported to exist for patients at age 45. She stated that judging from data obtained by Bausch & Lomb, the drop in acuity at age 45 is followed by an increase in acuity at age 50. Dr. Sloan remarked that perhaps the effect was the result of an unwise delay in procuring bifocals.

Dr. Scobee commented jpon the great importance of the illumination specification problem with reference to school children. As he explained it, it is desirable for the children to be able to perform their tasks without developing photophobia from high levels of illumination. He mentioned that the Subcommittee on Visual Standards must concern itself with problems of this sort.

Mr. Crouch expressed his belief that the Committee members might be interested in how the I.E.S. arrived at the recommended illumination level for school children, currently set at 30 footcandles (lumens per sq. ft.) of illumination. This high an illumination is necessary because much of the visual task assigned the children is reading pencil markings which is a fine detail of relatively low contrast.

Mr. Crouch reported that Weston's data at the 98% level yielded a recommended illumination of 28 footcandles under these circumstances of test object. He noted further that Tinker arrived at approximately the same level for this visual task, and that the Luckiesh visibility meter also yielded an answer comparable to the other methods.

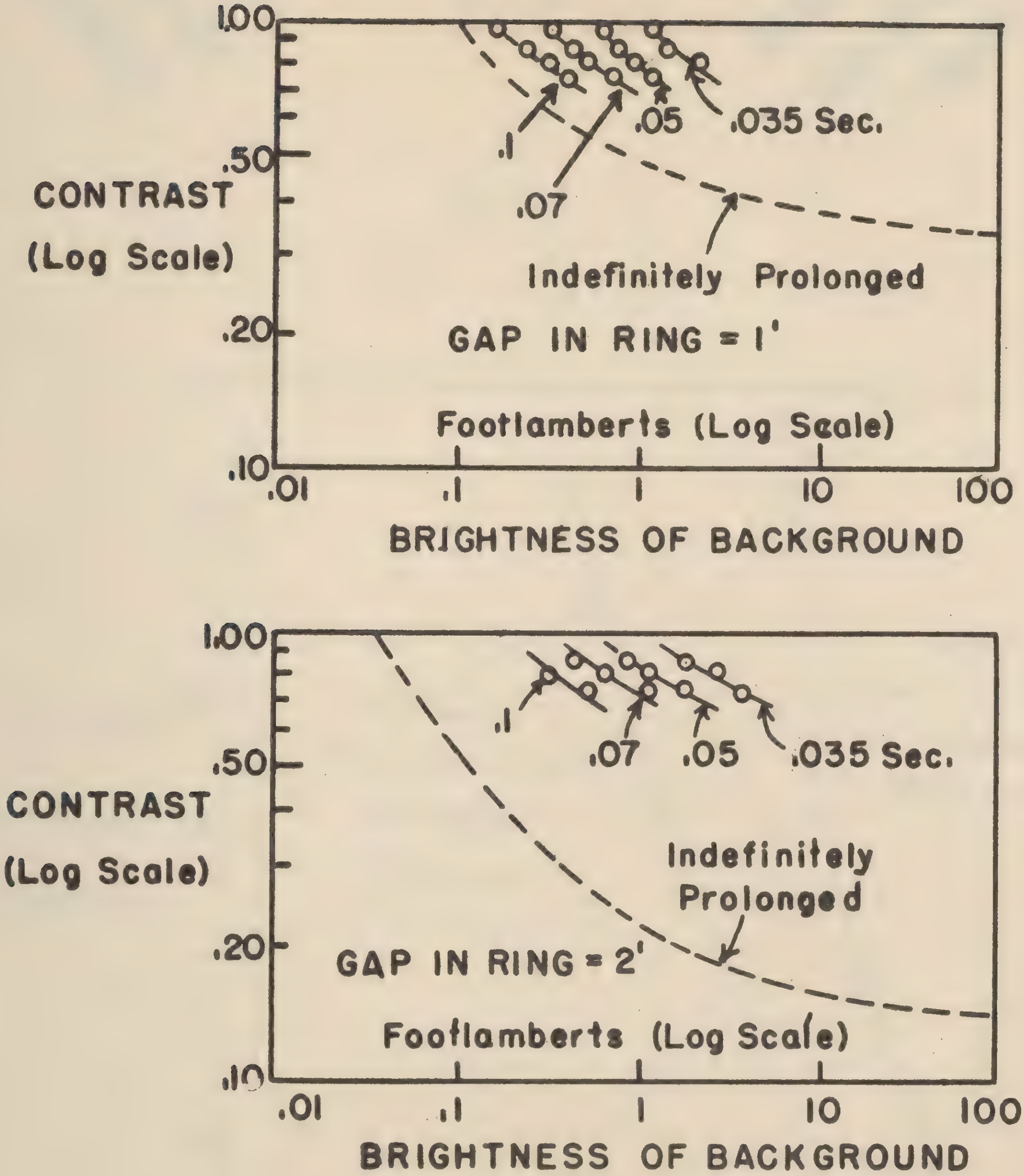
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Figure 1

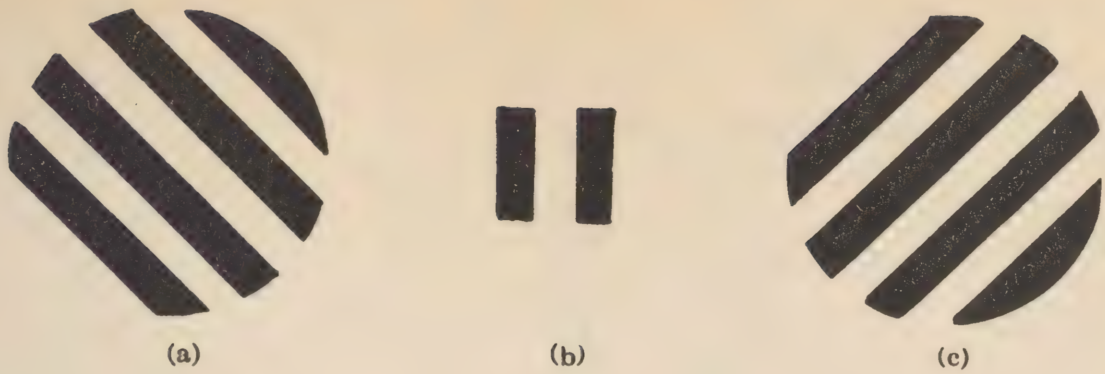


Figure 2

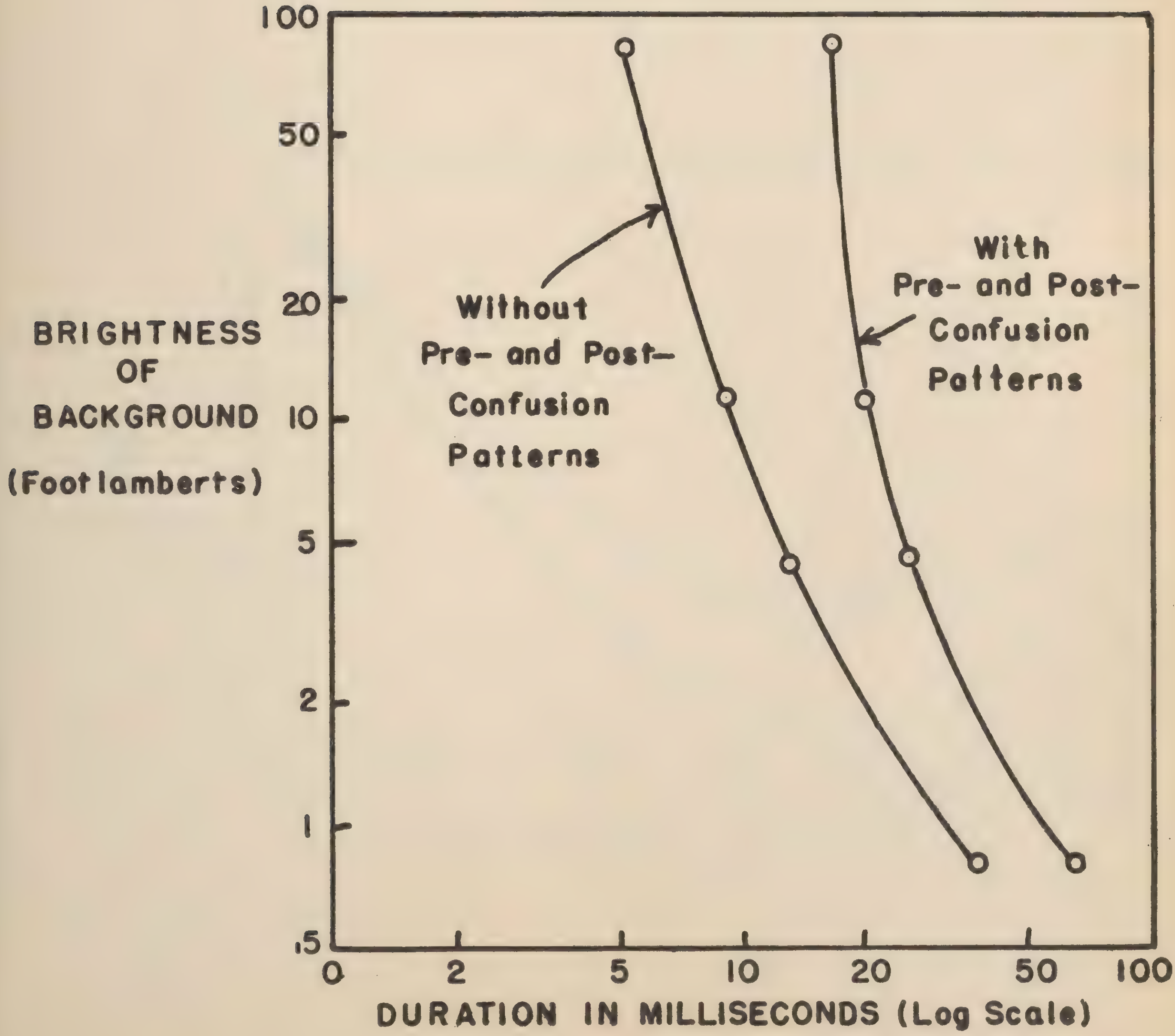


Figure 3

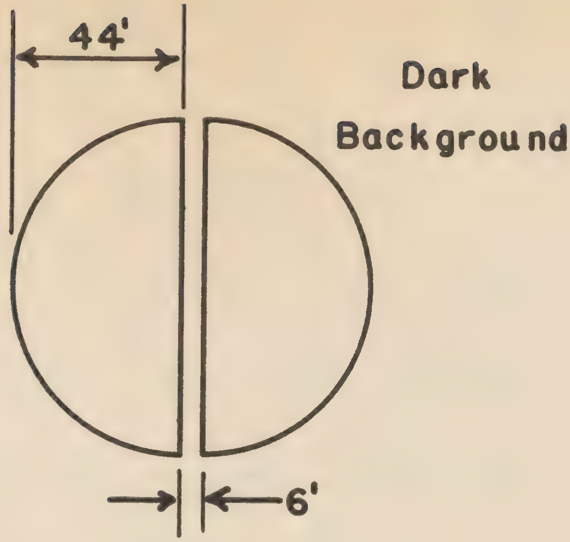


Figure 4

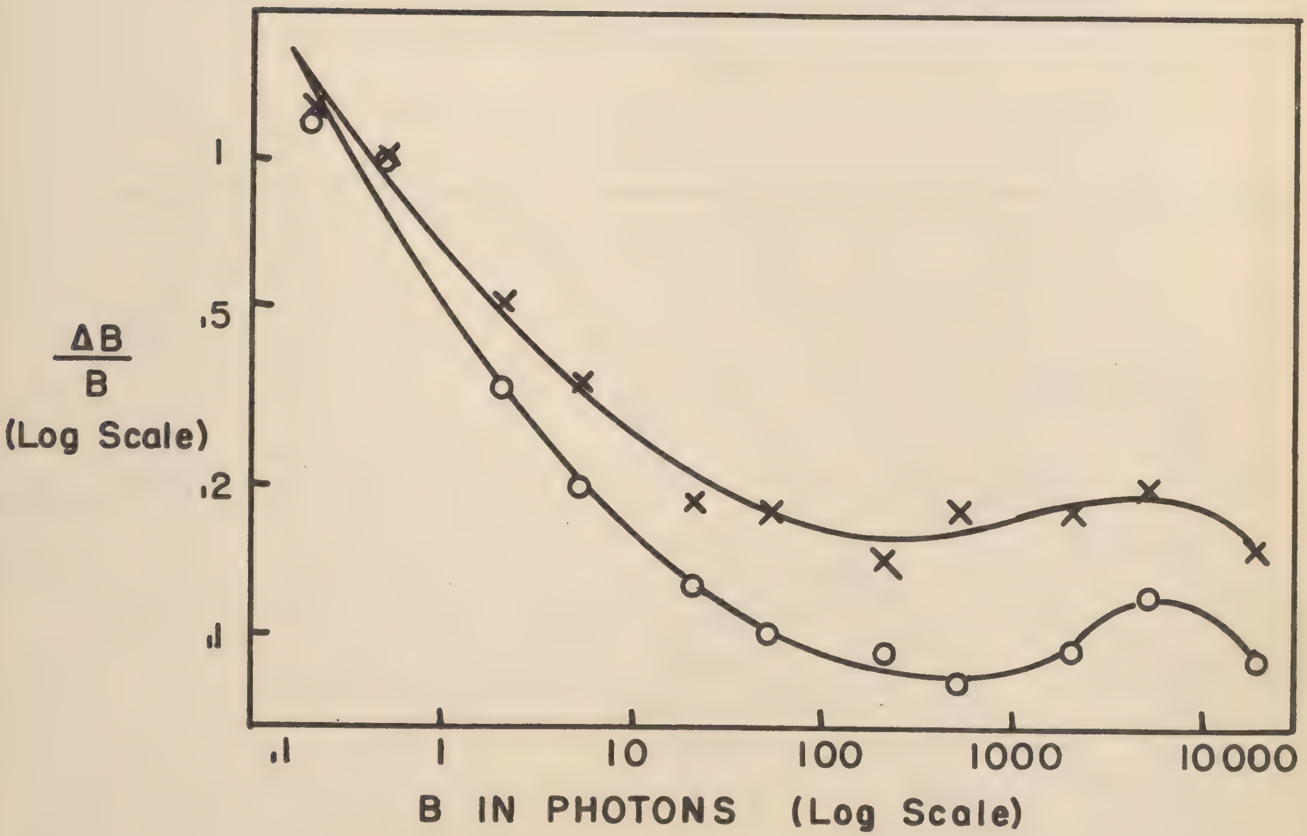


Figure 5

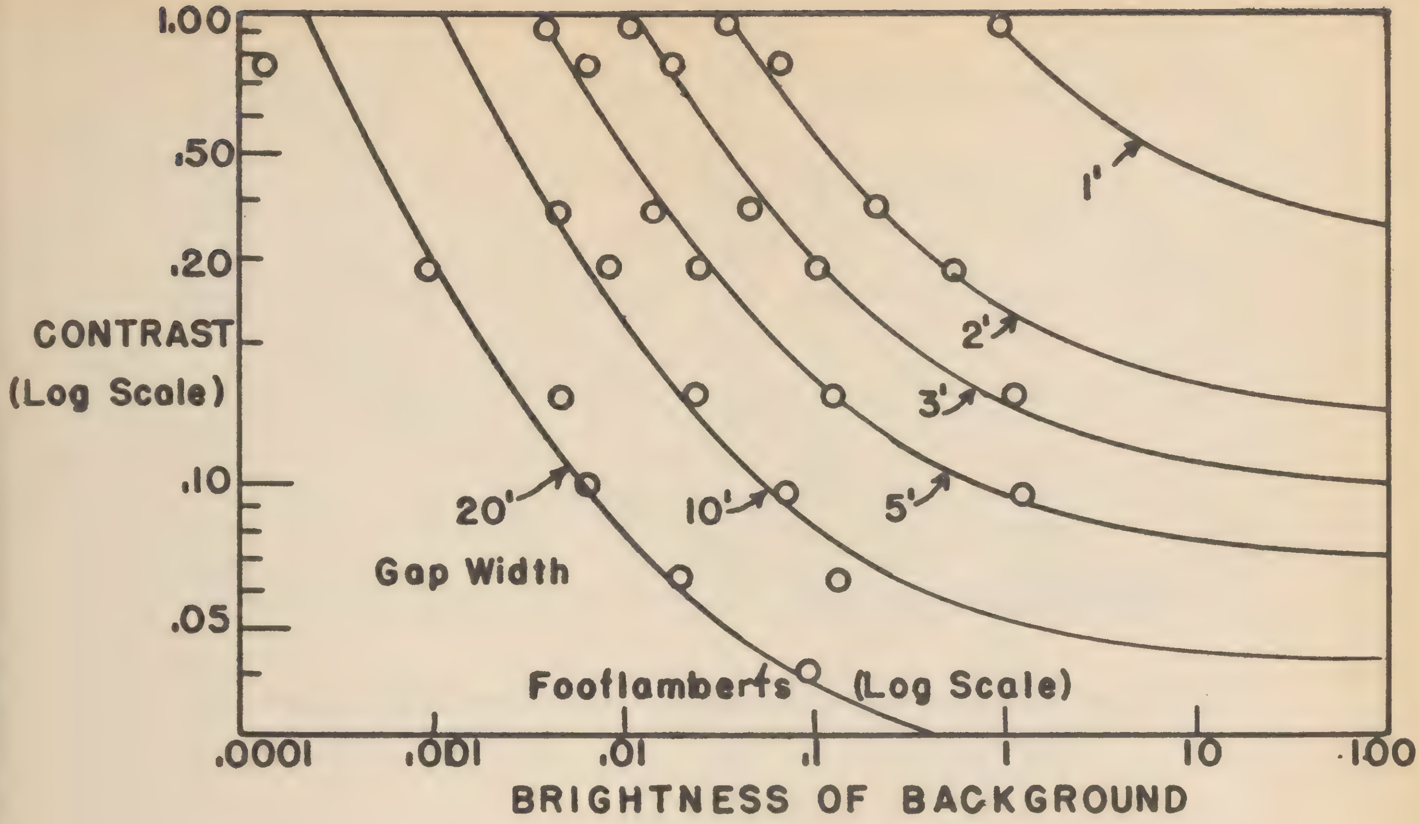


Figure 6

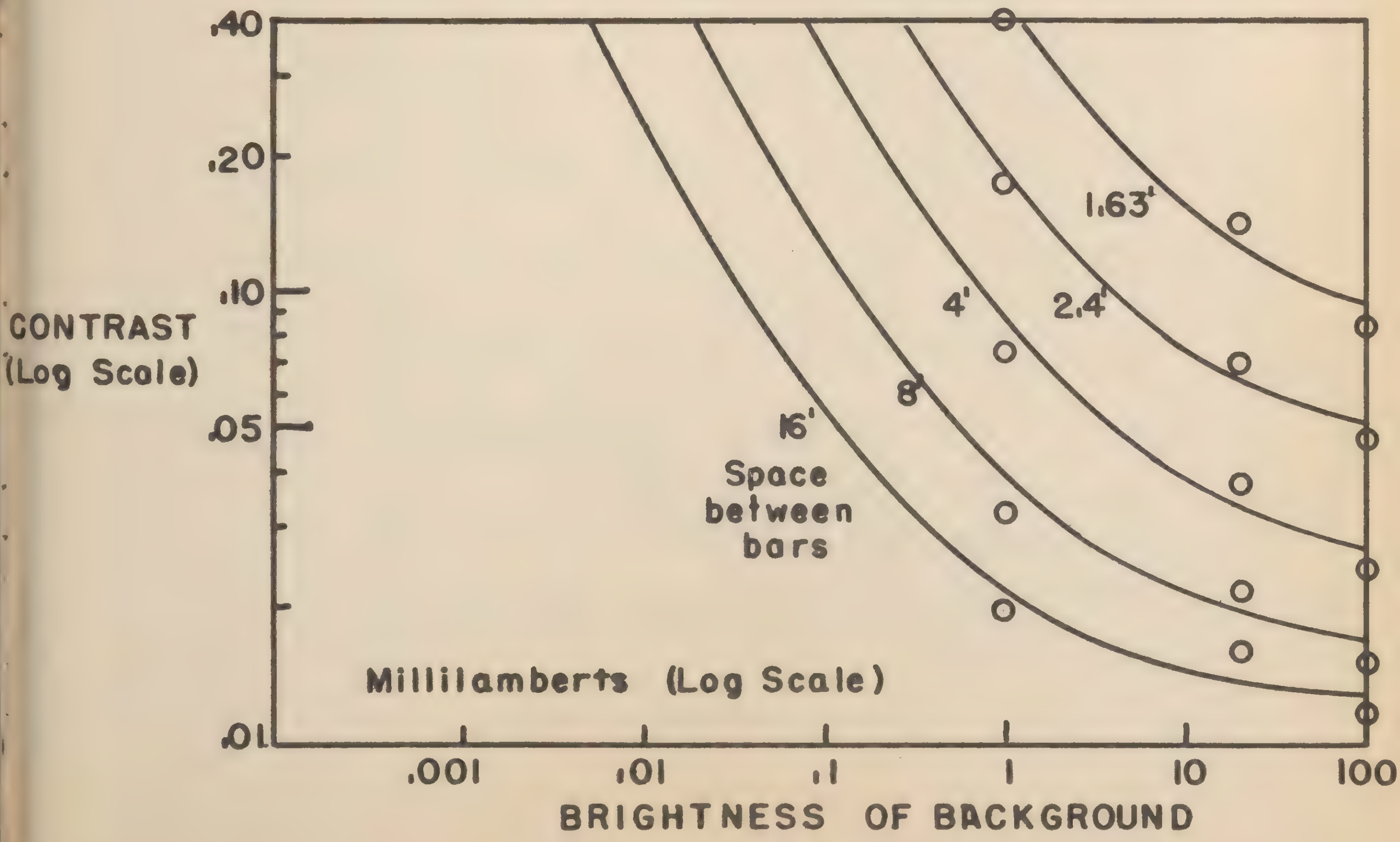


Figure 7

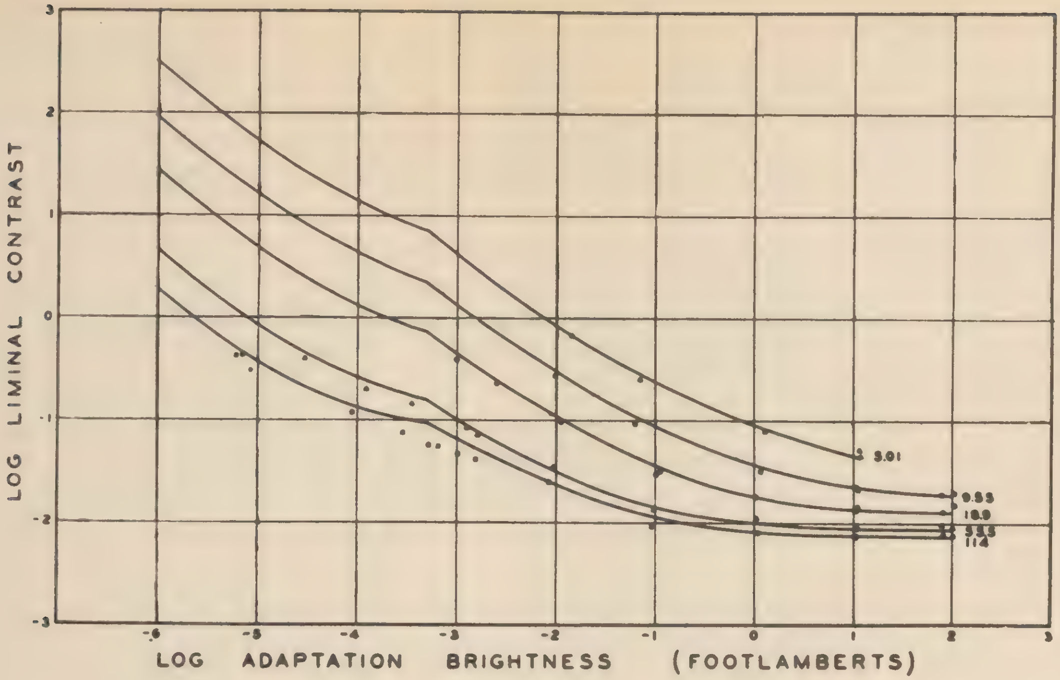


Figure 8

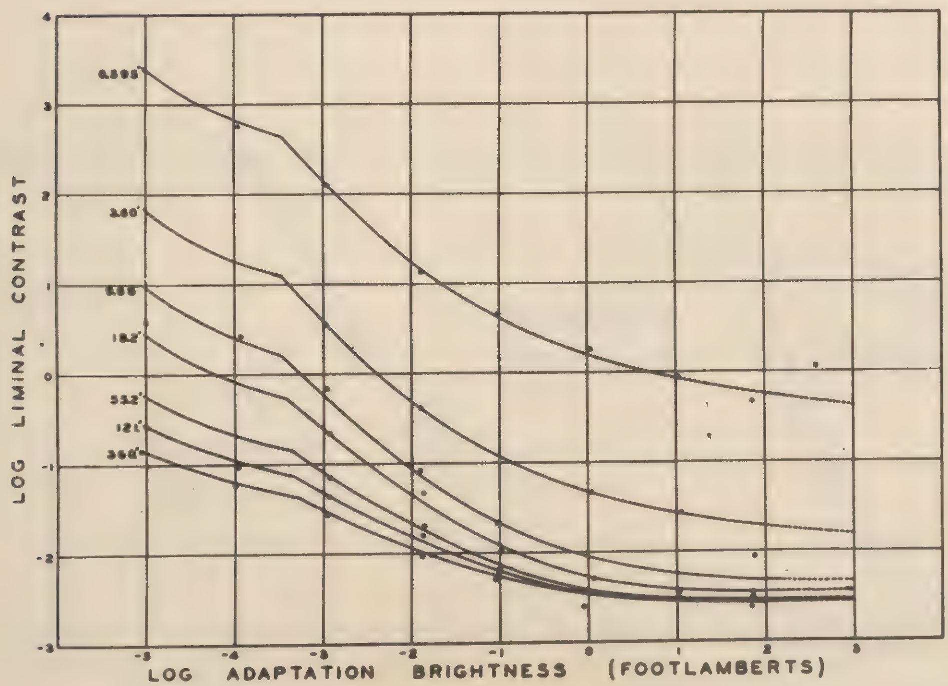


Figure 9

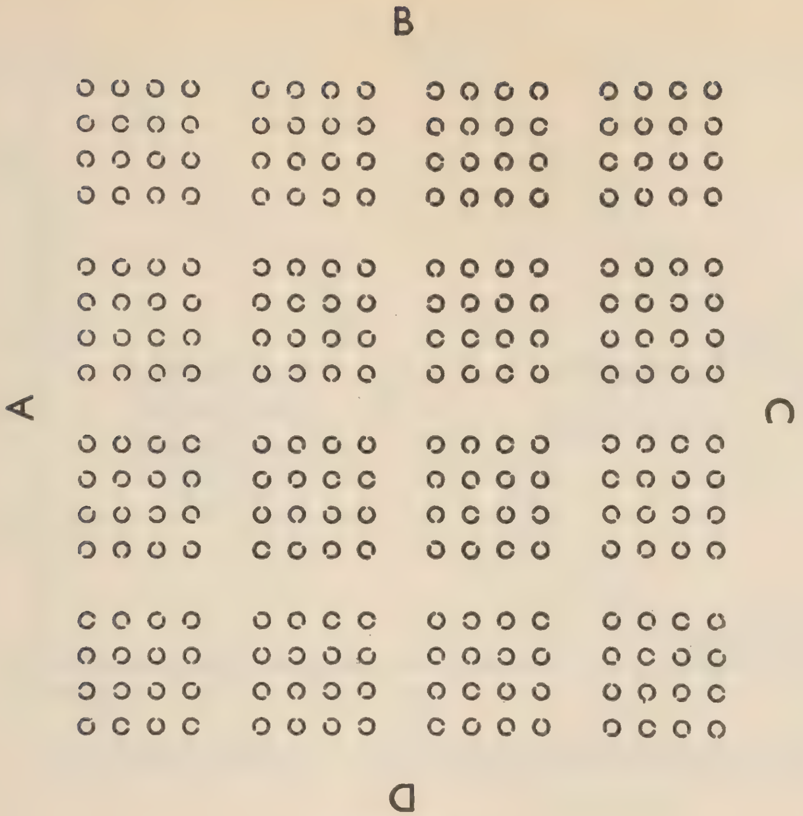


Figure 10

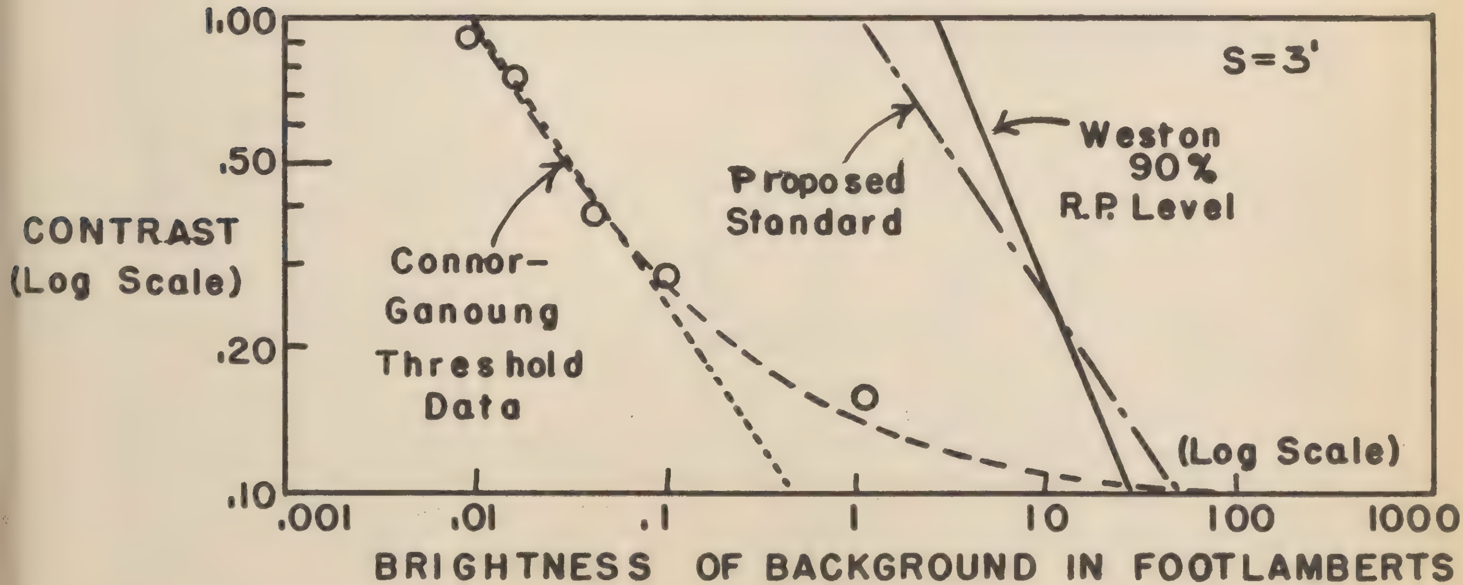


Figure 11

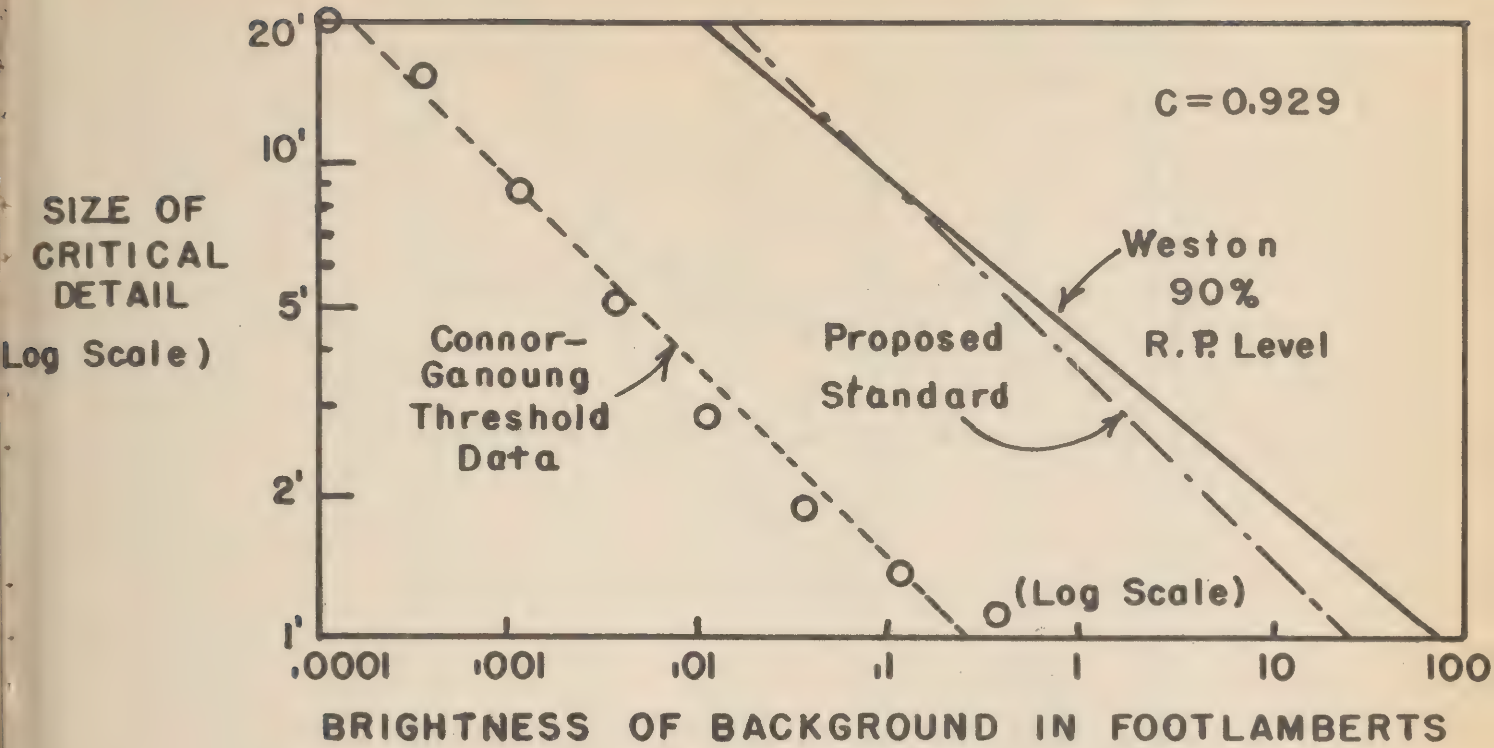


Figure 12

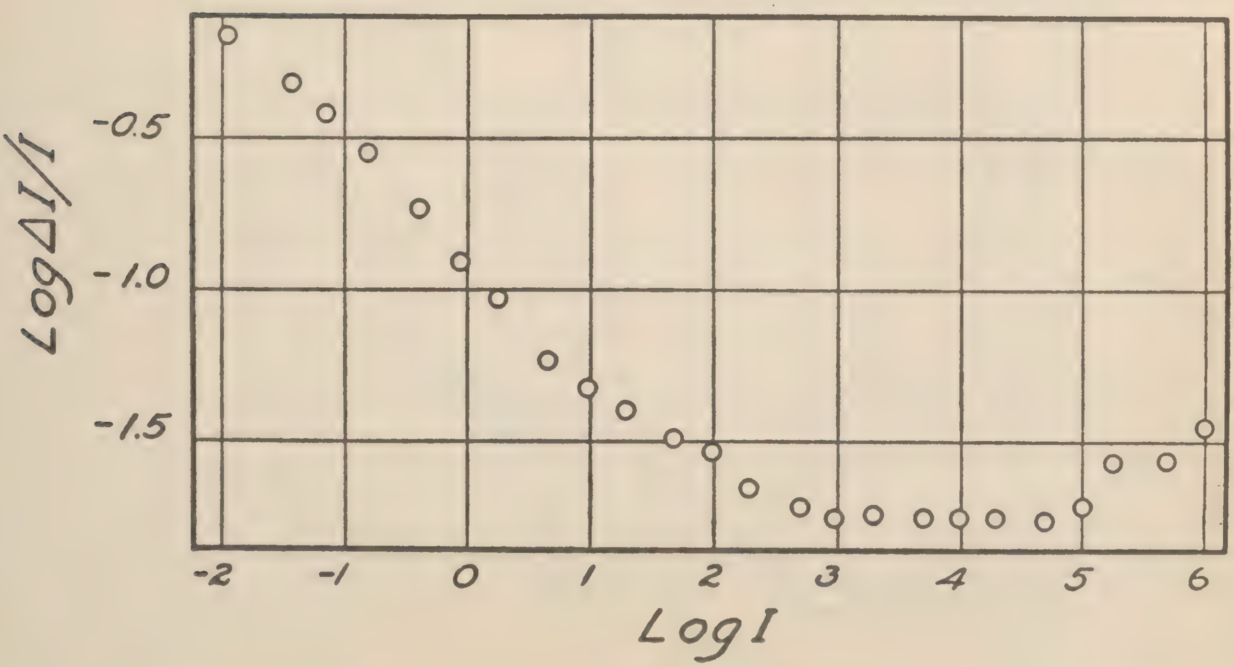


Figure 13

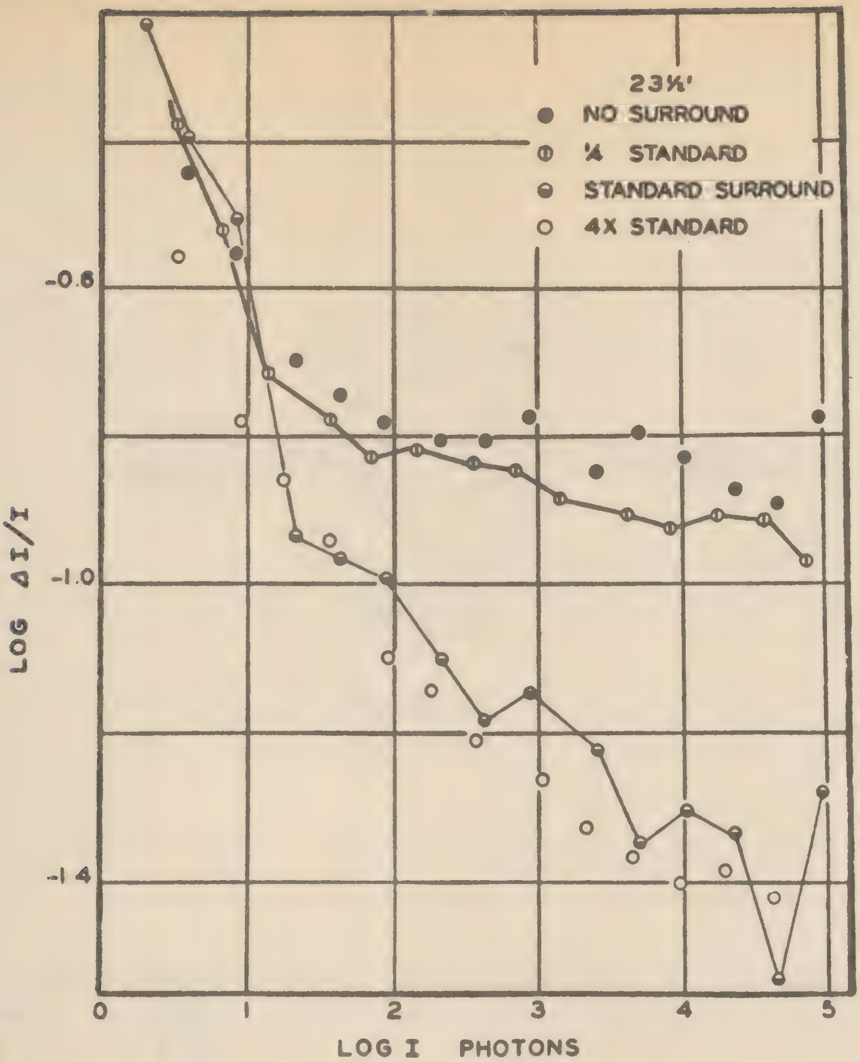


Figure 14

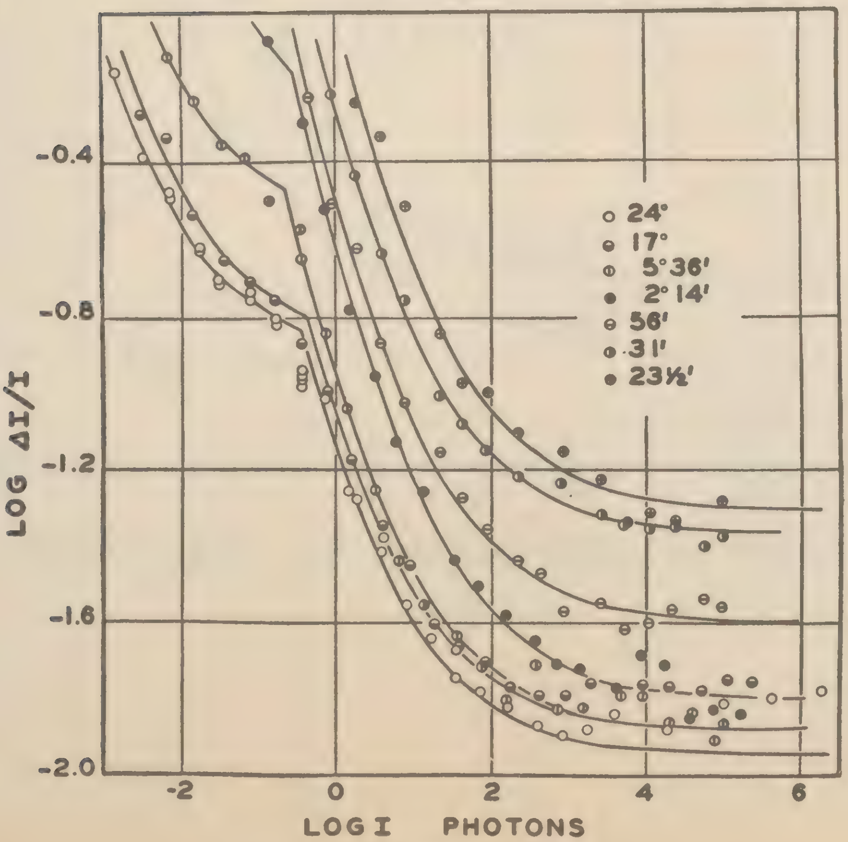


Figure 15

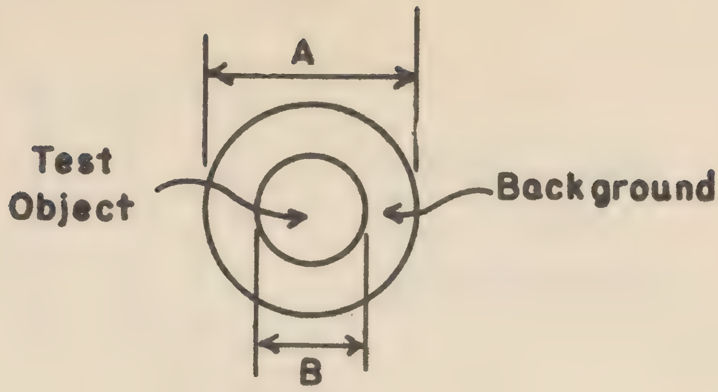


Figure 16

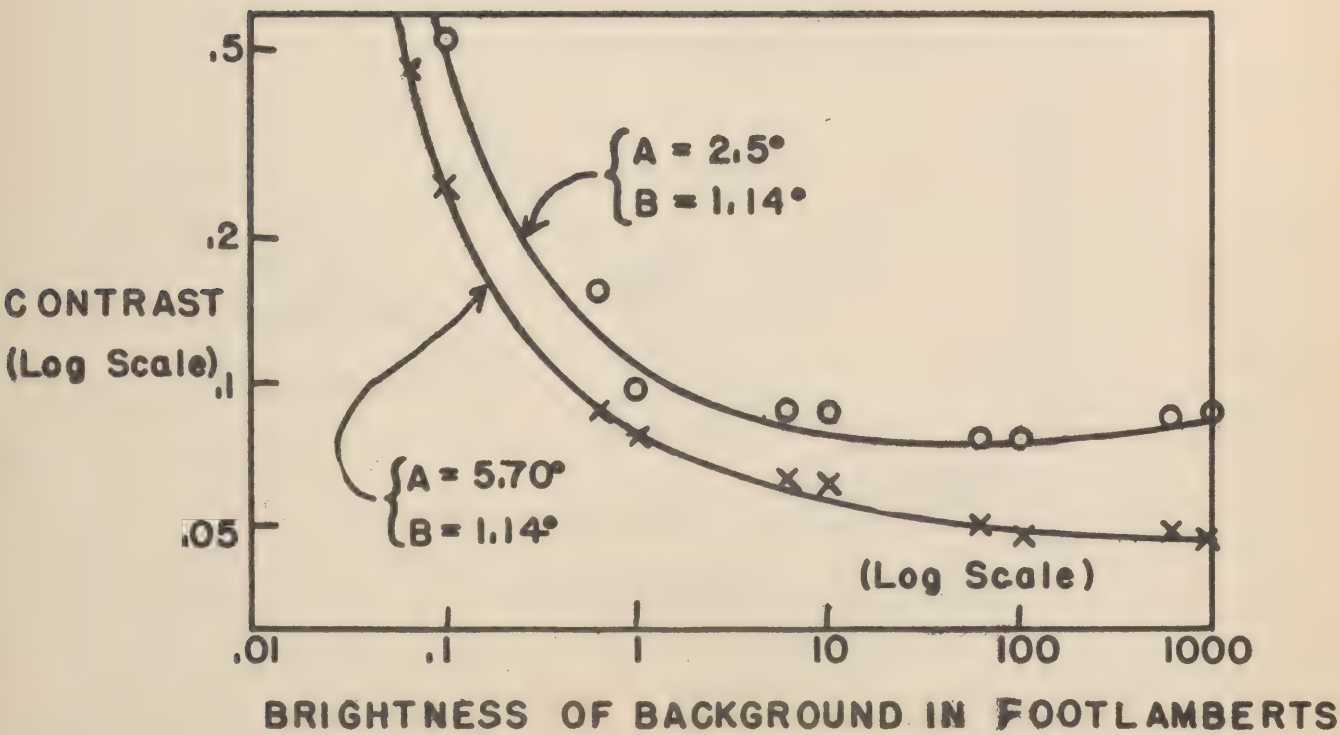


Figure 17

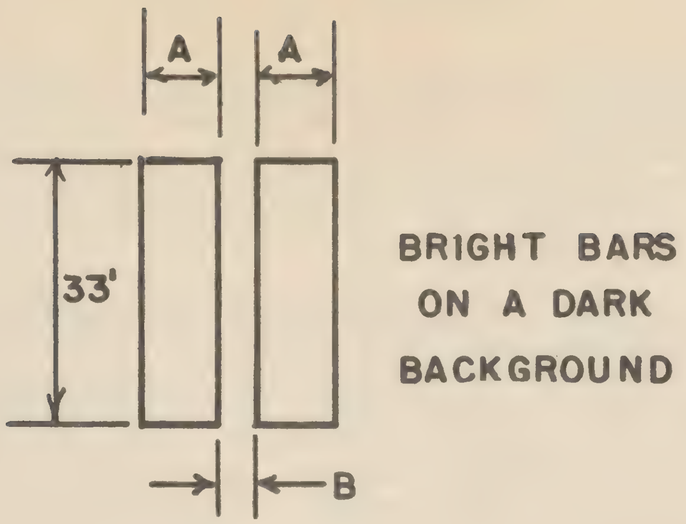


Figure 18

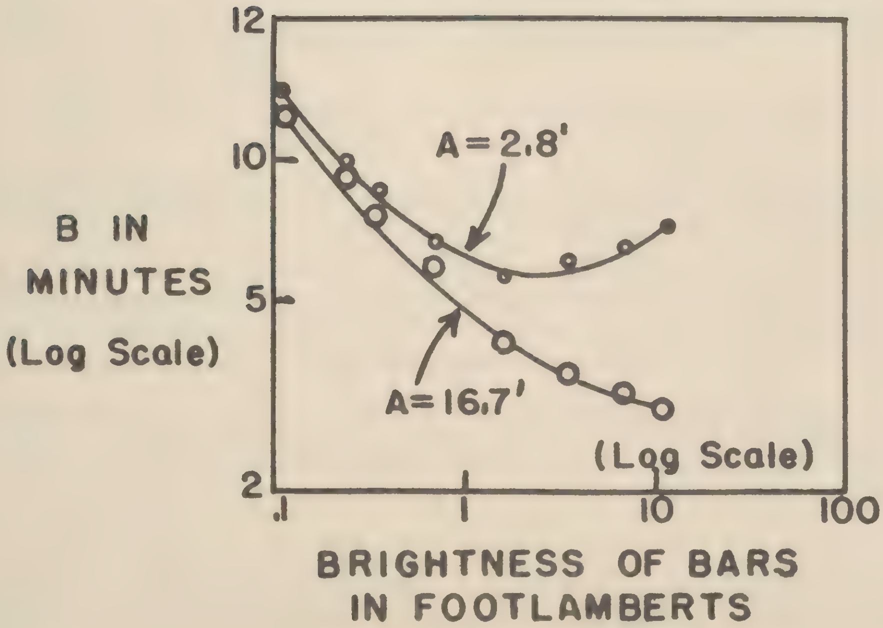


Figure 19

REPORT OF THE SUBCOMMITTEE ON COLOR VISION
by Deane B. Judd, Chairman

The personnel of the subcommittee has remained unchanged (Dr. A. Chapanis, Dr. F. L. Dimmick, Lt. Cmdr. Dean Farnsworth, Dr. D. B. Judd (Ch), Dr. Gertrude Rand, Dr. Louise Sloan). Its work during the past year has been to consider and to pass upon two proposals regarding color-vision tests referred through official channels to the subcommittee by Dr. Henry Imus, Office of Naval Research.

Dvorine Color Discrimination Screening Test. The first proposal was that a two-chart test of the pseudo-isochromatic type developed by Dr. I.Dvorine be adopted for screening the applicants for the Naval service. The members of the subcommittee were familiar with these charts and voted unanimously to disapprove the proposal because: (1) the test-retest correlation of the Dvoring charts is considerably lower than that obtained with the pseudo-isochromatic charts (American Optical Company charts) now being used for Screening applicants for the Naval service, (2) the correlation between the results obtained by the unvalidated Dvoring charts and other tests that have been satisfactorily validated has been found not to be high, and (3) it is considered that no two-chart test is at all likely to be reliable.

Freeman Illuminant-stable Color Vision Test. The second proposal was that the Office of Naval Research undertake the further development of a color-vision test of the pseudo-isochromatic type valid for a considerable range of artificial and daylight illuminations along the lines started by Dr. Ellis Freeman.[1] The present chart test used by the Armed Forces

1 Ellis Freeman, An illuminant-stable color vision test, I, J. Optical Soc. Amer. 38, 532, (1948).
Ellis Freeman and M. A. Zaccaria, An illuminant-stable color-vision test, II, Experimental-statistical evaluation, J. Opt. Soc. Amer. 38, 971 (1948).

(American Optical Company charts) is composed of somewhat imperfect copies of German (Stilling) and Japanese (Ishihara) charts. These charts were designed to be used under daylight illumination or a close approximation thereto. It has been abundantly proven that, while they are valid under this intended illumination, they fail to detect red-green confusers of the second kind (deuteranopic) if incandescent-lamp light be used instead of daylight.[2]

2 Dean Farnsworth and J. D. Reed, The effect of certain illuminants on scores made on pseudo-isochromatic tests, Color Vision Report No. 4, Medical Research Laboratory, New London, 24 December 1943; reissued 1 December 1948.
L. H. Hardy, G. Rand, M. C. Rittler, Effect of quality of illumination on the results of the Ishihara test, J. Optical Soc. Amer. 36 (1946)

If the currently available pseudo-isochromatic charts are to be used when average natural daylight is not available, suitable artificial daylight must be provided.[3] A series of six printing inks, ranging from strong orange to

3 D. Farnsworth and P. F. Kimble, Abridgment and administration of the A. O. 1st edition pseudo-isochromatic plates, Color Vision Report No. 14, Medical Research Laboratory, 9 December 1946

strong yellow, were developed for Dr. Freeman by the International Printing Ink Corporation. These inks were shown in Dr. Freeman's first paper[1] to have colorimetric characteristics such that they could easily be distinguished

by observers with normal vision regardless of the color temperature of the illumination between the limits 2,850 and 14,000°K, and at the same time would be indistinguishable, or nearly so, by both forms of red-green confuser (proto-form and deutero-form). It would appear probable from this report that a series of pseudo-isochromatic charts could be produced by means of these inks resulting in a screening test for red-green confusers not requiring any special artificial daylighting equipment for use when average natural daylight is unavailable.

The paper by Freeman and Zaccaria[1] reported on the results obtained by testing 100 color-blinds and 100 subjects of normal color vision by means of a series of 17 pseudo-isochromatic plates made up from various combinations of the six inks and a selection of plates from the American Optical Company test.[4] The test intended to be illuminant-stable was made up by punching disks out of papers colored by the inks and pasting them on 17 cards in a uniform pattern so that from one to three numerals were represented on each plate with no variation other than that of colors. The color-blind subjects were volunteers who responded to an advertisement for color-blind subjects in the University of Texas paper.

4 L. H. Hardy, G. Rand, and M. Rittler, A Screening test for defective red-green vision, J. Optical Soc. Amer. 36, 610 (1946)

Although the results indicated that the test worked about as well with incandescent-lamp light as with Macbeth artificial daylight as intended, the members of the subcommittee were puzzled by some of the other aspects of the results: (1) the Freeman test, unlike the A.O. test, was found not to be perfectly valid, that is, it misclassified a number of the subjects, many normal observers failing to read the plates correctly, (2) the A.O. test, not intended for use with non-daylight illuminants, performed nearly as well as the Freeman test, and (3) although each subject was retested, no test-retest correlations were available. In an effort to discover why such promising test material gave such disappointing results, an inquiry was made of Dr. Freeman as to what was the distribution of protoform and deutero-form defects among the 100 color blind subjects. The unexpectedly good performance of the A.O. plates suggests that the color-blind subjects tested were preponderantly of the proto-form type, and since it is likely that the color-blind subjects knew about their vision from tests by the Armed Services by techniques unsuited to detection of the deutero-form of defect, this suggestion is fairly plausible. Dr. Freeman was unable to supply this information; nor was he able to supply a copy of the 17 charts making up this test, nor a diagram showing the pattern used so that the members of the subcommittee might see whether defects other than choice of inks might explain the disappointing result. Dr. Freeman did report, however, that he had discovered errors in procedure of the statistical study after publication of the report, and he requested that the second paper be not considered in coming to a decision on the proposal.

The subcommittee voted (4 out of 5) not to recommend further development of an illuminant-stable color-vision test according to the present proposal, but it was the consensus of opinion that another proposal with better prospect of successful development of an illuminant-stable color-vision test might be worthy of recommendation on a rather non-urgent basis.

DISCUSSION:

Dr. Fry raised the question of whether an illuminant-stable color vision test was desirable. He stated his opinion that an illuminant-sensitive test aids the discrimination of color defectives because of changes in their luminosity function.

Dr. Judd reported Dr. Chapanis' opinion that a color vision test could not be devised which was illuminant-stable.

Mr. Harrison proposed a problem for the consideration of the group as follows: He stated that at meteorological stations, estimates of visibility are made at night on the basis of the distance at which colored runway lights can be seen. If the meteorological observers are color defective, very anomalous visibility ranges may thus be obtained. Mr. Harrison asked whether it would be possible to establish a test for color vision for meteorological observers which would eliminate this anomaly in visibility range determination.

Dr. Sloan asked whether the meteorological observers were required to recognize the color of the light or just detect its presence.

Mr. Harrison replied that the observers were required only to detect the presence of the lights.

Dr. Sloan stated that under these circumstances, the SAM Color Threshold Tester could not be used for the task without modification. The Threshold Tester has the advantage that it utilizes point sources, which represent the visual task put to the meteorological observers. The threshold tester is based, however, upon color recognition rather than mere detection of presence.

Dr. Sloan commented that only the protanomalous would be expected to give ambiguous results because the luminosity function for the dueteranomalous is very similar to the luminosity function for the normal.

Mr. Middleton expressed his belief that the color vision testing aspect of Mr. Harrison's problem was not as important as the inadequate adaptation utilized by the meteorological observers during the nighttime visibility estimates. As Mr. Middleton stated it, the observers go from relatively high levels of illumination into the night, and make their visibility observations soon after. Under these circumstances, Mr. Middleton expressed his opinion that differences due to inadequate adaptation would be far greater than differences between normal and color anomalous. He stated his belief that for night time visibility estimates, visual estimates have to be replaced by physical measurements.

Mr. Breckenridge pointed out, in addition, the large-scale errors in visibility estimates which can occur with runway lights because of their peaked candlepower distributions. This characteristic of the lamps results in radically different estimates of visibility, depending upon the angle of view of the observer, with respect to the maximum candlepower distribution.

DAYLIGHT DUPLICATION INDEX REQUIREMENTS FOR AVIATION SUN GLASSES
by Deane B. Judd

Reports of studies bearing on the optical properties required of the materials used for sun glasses have frequently been presented before this Committee and several of them[1] have spôken of the need that color perception

1 R. M. Toucey, Proposed standardized sunglass design, 5th Meeting, p. 9 (September 16, 1944),
R. H. Peckham, Solar transmission of glass and plastic used in sunglasses, 5th Meeting, p. 12 (September 16, 1944),
John L. Matthews, The effect of ophthalmic filters on color vision, 22nd Meeting, p. 21 (November 11, 1948).

of objects and lights be not importantly interfered with by selective absorption of the sunglass material. It is well recognized that rendering of objects in their true daylight colors is strictly possible only if the material be spectrally nonselective, that is, if its spectral transmittance be constant throughout the visible spectrum.

Exactly how much spectral selectivity can be tolerated for a given job is not known; nor, of course, are the more complicated requirements for a general purpose sunglass known. As a start toward procuring an answer to this question, an important study was carried out by Lt. Cmdr. Farnsworth[2] on the influence on color discrimination produced by five goggle materials

2 Dean Farnsworth, The effect of colored lenses upon color discrimination, Color Vision Report No. 9, Medical Research Laboratory, New London, 3 September 1945

of current interest (B & L Neutral, Calobar, Polaroid Neutral, Rose Smoke, Noviol). The method was to administer to 20 subjects, both with and without these goggles, the Farnsworth-Munsell 100-hue test of color perception. The results indicated that the B & L Neutral exercised only a slight influence on color perception while the Noviol produced a major impairment. The other goggle materials were intermediate in the order named above.

As a result of this work there arose among the cognizant officers of the Navy Department the view (communicated to me by Dr. Henry Imus) that Naval requirements would be served satisfactorily by the B & L Neutral material, but the Rose Smoke and Polaroid neutral materials studied by Farnsworth were considered to give too poor a rendering of the daylight colors of objects for the use of Naval aviators.

The question of how to write this property of a goggle material into a purchase specification then arose; and fortunately the most prevalent fallacious idea of how to do this had been exposed in the Farnsworth report. Since the ideal material for correct color rendition is spectrally nonselective, it must also have a neutral or gray color. It is easy, therefore, to jump to the conclusion that the desirability of a material may be measured by the degree to which its color approximates the true neutral. Farnsworth's results showed, however, that the Polaroid neutral (greenish gray) was distinctly poorer in color rendition than the Calobar (green). Gray materials having high spectral selectivity of transmittance can be just as objectionable in object-color rendition as non-gray materials. Furthermore, the Calobar material departed from neutral by about the same amount (Munsell chroma about /5) as the Rose Smoke material, although the latter produced much poorer object-color rendition.

Since it is recognized that object-color rendition is fully determined by the variation of transmittance with wavelength, it is a temptation to a specification writer to draw two spectrophotometric curves as tolerance limits and to say that materials having spectrophotometric curves falling between these two shall be deemed acceptable. It may be instructive to follow out this idea in relation to the Farnsworth findings. Note first that the Calobar material was found by Farnsworth to be nearly, or quite, as acceptable as the B & L neutral material. Since the spectrophotometric curve of the Calobar (green) material is lower at the ends of the spectrum (400 and 700 mμ) by about a factor of 4 than it is in the middle, the tentative transmittance tolerances must be set much higher at the extremes of the spectrum than would be at all reasonable for the middle. This idea is not too frightening by itself because it is obvious that spectral transmittance outside the visible spectrum does not bear at all on the question of object-color rendition, and it is reasonable to suppose that near the visible extremes the tolerances could be set much higher than at the middle. However, after the tentative tolerances have been set at the ends of the spectrum so as to admit the Calobar material, the specification writer will note with alarm that these same tolerances will admit also the inadmissible Rose Smoke material. No simple way exists of writing object-color rendition tolerances directly in terms of spectral transmittance.

It is also obvious that, although the Farnsworth method permits one goggle material to be rated relative to another for rendition of the daylight colors of objects, it is not a practicable method for insertion into a purchase specification. Farnsworth pointed out, however, that a method developed by Judd[3] or some modification thereof[4] had been suggested in a report from the National Bureau of Standards as possibly applicable to the specification of object-color rendition for goggle materials. As a result of this suggestion, the National Bureau of Standards was requested[5] to consider application of the duplication index to the setting of manufacturing tolerances on sunglass materials and to submit recommendations. Accordingly a study was made at the National Bureau of Standards, and it was found that the duplication index does indeed correlate well with the findings of the Farnsworth report.

3 D. B. Judd, Definition and tolerances for artificial daylight for color matching, J. Optical Soc. Amer. 29, 145 (1939),

4 D. Nickerson, The illuminant in color matching and discrimination, Illuminating Engineering (March, 1941)

5 Report of Conference No. 34-46 on Proposed Revision of ANA Specification AN-G-22, Bureau of Medicine and Surgery, Washington, D.C., 5 June 1946

The duplication index is based upon the principle that if one illuminant is to be considered a duplicate of another for color-matching purposes, it must preserve the same object-color differences. In other words, if one of two objects appears just noticeably redder than the other in daylight, it should also appear just noticeably redder in a satisfactory duplicate of daylight. And if by daylight two objects appear indistinguishable, the color difference between them should remain zero for the illuminant which is intended as a duplicate of daylight. Four pairs of test objects were used in the duplication index[4], a pair of blue painted surfaces and a pair of brown painted surfaces both pairs showing marked differences in spectral reflectance near the long-wave (red) extreme of the visible spectrum (Bittinger camouflage paints), a pair of green textiles differing markedly in the short-wave (violet) extreme, and a pair of olive textiles differing markedly in reflec-

tance in the middle (green) and long-wave (reddish orange) parts of the spectrum. The duplication index was based upon the degree to which the color differences between these four pairs of objects remained unchanged from one illuminant to another. The color differences were evaluated by means of the uniform-chromaticity-scale Maxwell triangle.[6]

6 D. B. Judd, A Maxwell Triangle yielding uniform chromaticity scales, J. Research NBS 14, 41 (1935); RP756 also J. Optical Soc. Amer. 25, 24 (1935).

In adapting the duplication index to the specification of goggle materials, three changes were made. First, since the desired perception of color differences is that characteristic of natural daylight, standard source C (representative of average natural daylight)[7] was taken as the reference illuminant, and the name daylight duplication index was used. Second, the pair of brown painted surfaces was found to add no information to what is already yielded by the pair of blue painted surfaces· so the brown pair of test objects was dropped in the interest of shortening the calculations. And finally, it was found that the more easily computed variables of the Adams "chromatic valence" space[8] could be substituted for those of the author's UCS Maxwell triangle with no loss of validity. Recommendations were submitted to the Aeronautical Board on December 18, 1947 on this basis, and on April 28, 1948, the Air Force-Navy Aeronautical Specification AN-G-22a for Glasses; Flying Sun was released with these recommendations incorporated in it. Details of the calculation of daylight duplication index for goggle lenses are given in this specification.

7 D. B. Judd, the 1931 I.C.I. standard observer and coordinate system for colorimetry, J. Optical Soc. Amer. 23, 359 (1933).

8 D. Nickerson and K. F. Stultz, Color tolerance specification, J. Optical Soc. Amer. 34, 567 (1944).

The advantages of the daylight duplication index that make it suitable for specification purposes are: (1) it may be computed from the curve of spectral transmittance of the material throughout the visible spectrum, (2) it is necessarily 100% for any spectrally nonselective material, and its value decreases for goggles that are spectrally selective in those portions of the spectrum required for rendition of objects in their daylight colors, and (3) its rating corresponds well with the results of Farnsworth, thus: B & L Neutral 63, Polaroid neutral 57, Rose Smoke 39. The three pairs of test objects on which it is based are sufficiently varied in spectral character that by setting a minimum value of 60 on daylight duplication index for the neutral type goggle material, the Armed Forces can be assured of goggles yielding as good a rendering of objects in their daylight colors as that provided by B & L Neutral, judged by Naval officers on the basis of the Farnsworth tests to be suitable.

The daylight duplication index can be criticized because of the length of time (about 8 hours) required for evaluating it in accord with Table 3 of AN-G-22a and checking the computation. At a meeting at the National Bureau of Standards in October 1948 attended by representatives from Bausch & Lomb, Pittsburgh Plate Glass Co., Willson Products Co., L. J. Houze Glass Co. and American Optical Co., Specification AN-G-22a was discussed, and it was pointed out that this specification requires the daylight duplication index to be determined for each of 100 goggles selected from each lot of 5000. It was contended with some justification that this stipulation,

requiring as it does 100 man-days of work for the calculations alone, is excessive. Since increasing the thickness of the goggle material must increase its spectral selectivity, and thus lower its daylight duplication index, it is necessary only to test the darkest goggle lens made from each melt of glass. No useful purpose is served by testing other lenses from the same melt, because if the darkest passes, all must pass. Revision of AN-G-22a along these lines would seem to be called for, but since as a part of the unification of the Armed Forces the Aeronautical Board was dissolved shortly after issuing AN-G-22a, there was doubt as to how to proceed toward such a revision. This is a suggestion, however, for the consideration of whatever agency has cognizance of this specification.

The daylight duplication index is open also to two other criticisms. In the first place it has been validated only in the sense that goggle material meeting the minimum requirement of 60 can confidently be accepted as giving as faithful a rendition of object colors as B & L Neutral already found to be suitable. It is not known whether goggle material having an index of, say, 80 would be significantly better for the purposes of the Armed Forces. In the second place the question can legitimately be raised whether the three pairs of test objects, being sensitive as they are to differences over the whole spectrum, are really required for these purposes. Perhaps two or even one pair of test objects related directly to the most critical of the discrimination tasks to be performed by the goggle wearers in the Armed Forces, would be sufficient and would permit definition of a daylight duplication index requiring less calculation.

Research on goggle material is now under way at Temple University under the direction of Prof. R. H. Peckham according to the terms of a contract with the Office of Naval Research. It is hoped that this research work will meet these criticisms either by providing a basis for an improvement of daylight duplication index or by showing that no significant shortening of the definition can be made without impairing its validity.

DISCUSSION:

Commander Brown commented that in his opinion the one occasion on which aviators want sunglasses is when they are flying over a bank of stratus clouds. Under these circumstances there is no concern about color rendition, and the only important thing is that the general brightness be much reduced. Commander Brown suggested that perhaps this kind of use of sunglasses demanded different basic requirements for sunglasses than uses in which color discrimination was important. Perhaps the two uses might be better served by separate sunglasses. Commander Brown commented further that in his opinion the biggest problem about sunglasses was that aviators do not like to wear them at all except under uniform conditions of high brightness.

Dr. Judd replied that he agreed that color rendition made very little difference when an aviator is flying over stratus clouds. He expressed his belief that the essential problem was to protect the eyes of the aviator who has to fly long periods of time. One aspect of protection involves the absence of distortion of color perception sense. It should be recognized that the aviator could take the sunglasses off when he needed to see color.

Mr. Breckenridge asked whether Dr. Judd could not utilize a series of weights for a spectral transmission at various parts of the spectrum in order to reduce the calculational labor involved in computing the daylight duplication index.

Dr. Judd replied that such a procedure might be possible, but that he had not investigated the possibility as yet. He reported that the British separate the spectrum into eight or nine blocks and weight each by the average luminosity value. Such a procedure might be applicable to the daylight duplication index calculation. The discrimination of such a procedure would have to be tested against "good" and "bad" sunglasses.

The ONR Sponsored Program of Research in Vision

Henry A. Imus
Office of Naval Research

I. Introduction

The Psychophysiology Branch is supporting a planned program of fundamental and applied research in the human senses, involving the purposive behavior of man in response to stimuli under laboratory and field conditions as related to fundamental science and as related implicitly or explicitly to the science of Naval warfare. These aspects of sensation may be classified in part as dealing with the physics and chemistry involved in the transformation of energy into the sensory stimulus; the physiology and neurology of the human senses; the measurements and relationships of the various sensory functions; the psychology of sensation as the response of the human organism; the applications of psychophysiological principles in the development and use of training devices; the testing and selection of personnel by sensory methods; the protection of the sensory organs and adnexa from physical, chemical and radiational damage; and the human engineering, development and application of instruments to Naval operations and combat procedures. This planned program of research is included under the following categories:

- Anatomy, Physiology and Neuromuscular Functions of Vision
- Physiological Optics
- Perceptual Functions of Vision
- Rehabilitation of Vision

II. Brief description of each area of interest of the planned program according to Navy needs and requirements.

Anatomy, Physiology and Neuromuscular Functions of Vision

Research in these fields is basic to the adequate understanding and application of visual principles to the selection of the most efficient optical instruments and the selection of Naval personnel for duties requiring special visual qualifications. One of the urgent problems at present is the establishment of practical yet adequate standards of vision for various Naval billets. During the War, the requirements for stereoscopic rangefinder operators were established on the basis of an extensive research program. Similar research, including job analyses, needs to be done on many other billets.

Physiological Optics

The optical factors of image formation in optical instruments and in the human eye, and the modification thereof contributed by the physiological factors of the various media and sensory end-organs of the eye, influence the perceptual judgment of the personnel engaged in Naval operations. The study of physiological optics, therefore, is essential to the design of optical instruments, their operational application and the selection of personnel to use such equipment.

Perceptual Functions of Vision

The response of the individual to visual stimuli is controlled by the laws of visual perception as well as by a multitude of other psychological factors which affect the individual. The perception of form, motion, contrast, color and distance are of primary importance in lookout, observer, and search duty, the detection of

targets and camouflage and the guiding of missiles to the proper targets.

Rehabilitation of Vision

This problem is an extensive one because it involves the study of the sensory capacities of the blind, the learning processes of the blind and numerous devices and procedures for guiding and training these casualties of Naval operations and combat. In addition, adequate protective devices must be developed in order to prevent, as much as possible, such casualties.

ANATOMY, PHYSIOLOGY, AND NEUROMUSCULAR FUNCTIONS OF VISION

NR-141-017 Human Vision

Contractor: University of Pennsylvania, Philadelphia, Pennsylvania
Contract: N6onr-249, Task II, (4/15/46 to 6/30/49)
Investigator: H. K. Hartline

The purpose of this project is to investigate the physiology of vision by recording electrical activity in the optic nerve fibers of lower animals. Photoreceptor mechanisms of the visual sense cell and the organization of nervous activity in the layers of the vertebrate retina will also be studied. Specific problems will include brightness discrimination, light-and-dark-adaptation, "fatigue", threshold uncertainty, relation between spatial and temporal summation, and relation between rod and cone fuctions. Extension of methods to human eyes available from enucleation operations will be attempted. Parallel studies, by standard methods, of subjective observation will be made on human subjects. Consultative and other assistance to service laboratories will be furnished according to request. Specific problems on which assistance can be given include lighting problems, problems of night vision, optical distortion, characteristics of binoculars.

Progress to 12/31/48: An intensive program of experimentation on single optic nerve fibre activity (eye of Limulus) has been conducted. Preliminary analysis of the data suggests the following tentative conclusions:

(1) Studies of the inhibitory effect upon a visual receptor by the illumination of adjacent areas of the eye show clear evidence for the summation of inhibitory influences. This effect decreases with the distance from the given receptor.
(2) Transient changes in the frequency of impulse discharge elicited by small changes in illumination are comparable for equal intensity steps provided the final intensity level is the same.
(3) Frequency of seeing data at the threshold are consistent with those required by the statistical consequences of the quantum nature of light.
(4) Higher thresholds persist for several seconds even after a subliminal flash of light.
(5) Temporal summation fails after a critical time delay.

After 1 July 1949 this project will be transferred to Johns Hopkins University under a new contract because the principal investigator has been appointed Head of the Department of Biophysics at that institution.

NR-141-022 Binocular Neuromuscular Mechanisms

Contractor: Washington University, St. Louis, Missouri
Contract: N6ori-202, Task I, (9/1/46 to 8/31/49)
Investigator: R. G. Scobee, M.D.

The purpose of this project is to make (1) a study of all of the known variables in the Maddox Rod test of heterophoria; (2) a comparison of other tests of heterophoria with the Maddox Rod; (3) a study of the basic factors which influence heterophoria; (4) the relationships of the various portions of the muscle balance examination to the evaluation of the "muscle balance" as a whole; and (5) a study of the present diagnostic methods used in the measurement of heterotropia with the possible discovery of some better and more reliable diagnostic criteria.

Progress to 12/31/48: A reprint of a technical report "Relationships Between Lateral Heterophoria, Prism Vergence and the Near Point of Convergence," published in the April 1948 issue of the American Journal of Ophthalmology, has been distributed. A copy of another technical report "Some Practical Points About the Recession Operation," submitted to the American Journal of Ophthalmology, has been received. Research is continuing on eye-muscle imbalances and eye-muscle exercises.

NR-141-277 Chemistry and Physiology of Vision

Contractor: Harvard University, Cambridge, Massachusetts
Contract: N5ori-76, Task XI, (10/1/46 to 9/30/49)
Investigator: G. Wald

Under this project two lines of investigation are being pursued in close association with each other: (1) Measurements of the spectral sensitivity of human vision, cone and rod in various physiological states, and in normal and aphakic eye, and (2) the chemistry of the photoreceptor systems of the rods and cones and of other retinal components.

Progress to 12/31/48: A biography of Professor Selig Hecht, with a comprehensive bibliography of his 121 publications and a portrait, has been published by Dr. George Wald in the Journal of General Physiology, Vol. 32, September 1948, pp. 1-16. A technical report "The Photochemistry of Vision," from the Proceedings of the International Colour Vision Conference, held in 1947 at Cambridge University, England, will appear in Documents Ophthalmologica, Vol. 3.

Fundamental research on the spectral absorption of the ocular tissues is continuing.

NR-141-359 Study of Electrical Activity of the Human Retina

Contractor: Brown University, Providence, Rhode Island
Contract: N7onr-358, Task II, (9/29/47 to 9/30/49)
Investigator: L. Riggs

The purpose of this project is to study the perception of colors under low levels of illumination and conditions of fog, and to investigate color blindness by this new technique. It is hoped that this study will lead to basic understanding of the process of color vision and to practical application of these findings in the selection of personnel for night lookout duty, and the elimination of the color blind from the Naval service.

By means of recording the retinal action potentials picked up by an electrode fastened to the living eye by a contact lens, the response activity of the retina to light will be studied in both normal and color blind subjects. This will determine whether the deficiency occurs in the retina or in the higher brain centers. Similarly, the function of dark adaptation and of visibility for both normal and color blind eyes will be studied by measuring the electrical response of the retina to light of

different wave lengths and of different intensities.

Progress to 12/31/48: The sensitivity of the eye to various wavelengths of light has been measured by means of four procedures: (1) Scotopic matching, (2) flicker photometry, (3) electrical responses of the dark-adapted eye, and (4) electrical responses of the light-adapted eye. Technical reports are being prepared. Some experimental work has been delayed by the instability of the direct-coupled amplifiers. Steps are being taken to correct this defect.

PHYSIOLOGICAL OPTICS

NR-142-404 Visual Research

Contractor: Columbia University, New York, New York
Contract: N6onr-271, Task IX, (9/2/47 to 8/31/49)
Investigator: C. H. Graham

The purpose of this project is to make a study of vernier acuity in its various time and intensity relations. An apparatus and technique, developed at the Columbia Laboratory, will be used to measure instantaneous thresholds of a single retinal area while it is adapting to illumination. The data obtained will have a direct bearing upon the theory of visual photochemical processes.

The electrical activity which occurs when a single sense cell is illuminated will be studied by electrical recording methods using the horseshoe crab. Results with this preparation are not complicated by the activity of neural synapses, hence it is important to explore the effect of all parameters of the visual stimulation functions.

Neither theory nor data on the problem of monocular movement parallax are available in the literature on space perception. Experiments will be conducted on the effect of illumination, rate of movement, retinal position, size of target, and symmetry of object relations upon the threshold.

Progress to 12/31/48: Two technical reports have been submitted for publication: "Experimental Evidence on an Extension of Quantum Considerations to Visual Intensity Discrimination" and "Some Problems in the Analysis of Experimental Data," both by C. G. Mueller.

Research is continuing on the visibility functions of the human eye, figural after-effects, light adaptation and perception of curvature, monocular movement parallax, dark adaptation and light adaptation for various wavelengths.

NR-142-526 Screening Devices for Rapid Testing of Visual Functions

Contractor: Johns Hopkins University, Baltimore, Maryland
Contract: N6onr-243, Task VII, (3/1/48 to 2/28/50)
Investigator: L. L. Sloan

The purpose of this project is to make an investigation of the basic factors involved in measuring certain aspects of visual function, in particular, acuity, phoria, depth perception, and color discrimination. One purpose of the studies is to determine the experimental condition necessary to obtain reliable and valid measures of visual functions by means of visual screening devices. Other visual tests will be evaluated, i.e., night vision, peripheral vision, etc.

Progress to 12/31/48: New slides have been developed and are being procured for the testing of visual acuity, heterophoria and depth perception. The work on color perception has been delayed pending the modification of the New London Navy Color Lantern. The manufacturers of the industrial vision screening devices are cooperating in the preparation of the new test slides.

NR-142-565 — The Influence of Certain Sunglasses on Object-Color Perception

Contractor: Temple University, Philadelphia, Pennsylvania
Contract: N8onr-560, (3/1/48 to 5/31/49)
Investigator: R. H. Peckham

The purpose of this project is to determine, by experiment, the perception of object-colors through colored or tinted sunglasses. Standard sunglasses will be used in varying thicknesses in order to change the transmission from five per cent to 50%. The adaptation of the eyes to the sunglasses will be computed by both the Munsell and Judd methods. The relative completeness of adaptation will be checked empirically and the effect of the lenses on color perception will be determined experimentally.

Progress to 12/31/48: A technical report will be available early in the Spring.

NR-142-710 — Visibility of Submerged Objects

Contractor: Massachusetts Institute of Technology, Cambridge, Mass.
Contract: N5ori-78, Task XXXI, (6/1/48 to 3/31/50)
Investigator: S. Q. Duntley

The purpose of this project is to obtain adequate data on various physical factors so that engineering methods can be applied to the visibility of submerged objects. In particular, it is necessary to investigate the refractive effects of the surfaces of bodies of water and the contrast reduction by reflections from such surfaces. Photometric observations will be made of a variety of submerged objects at various depths and azimuths under a wide range of lighting and weather conditions. Both photographic and visual photometry will be used. From these exploratory experiments a means for specifying the physical factors in question in terms of the state of the sea and the state of the sky, measured by parameters which can be evaluated easily, on shipboard or estimated from meteorological data, will be evolved.

Progress to 12/31/48: Analysis of preliminary data collected during the summer of 1948 indicates the value of continuing this field study for another year. Dr. Duntley's report is presented elsewhere in these minutes.

NR-142-790 — Polychromatic Plates for Testing Color Vision

Contractor: Columbia University, New York, New York
Contract: N8onr-70200 (11/1/48 to 10/31/49)
Investigator: L. H. Hardy

Printed copies of polychromatic plates developed by the Knapp Memorial Laboratories will be tested and validated against the Navy Color Lantern and other color vision tests. Both normal and color defective subjects will be used under standardized test conditions.

Progress to 12/31/48: Printed polychromatic plates for validation are being procured.

PERCEPTUAL FUNCTIONS OF VISION

NR-143-106 Probability of Detection and Recognition of Visual Targets

Contractor: University of Michigan, Ann Arbor, Michigan
Contract: N5ori-116, Task V, (7/15/46 to 10/15/49)
Investigator: H. R. Blackwell

This project was undertaken at the request of Dr. H. R. Blackwell, who wished to make a check, under field conditions, of visibility data which he collected in the laboratory at the Tiffany Foundation.

The purpose of this project is to obtain engineering data for normal human binocular vision, to be used in various practical military situations in which visual detection and recognition are involved. Initial studies will be made in which the relation between brightness contrast and stimulus exposure is determined for objects differing in size, shape, and location in the visual field. Data are to be obtained utilizing the psychophysical method of constant stimuli so that the entire curve of probability can be determined. The relation between binocular and monocular thresholds will also be determined. An investigation will be made of the effect of the steepness of the stimulus gradient and the effect of training upon visual thresholds.

Initial work will be designed to establish the most valid use of psychophysics.

Progress to 12/31/48: During the summer and fall, a series of measurements of visual thresholds were made in a field installation located in the forested area of northern Michigan. Targets varied in distance from six to 30 miles from an observation post. Measurements were made, day and night, with naked eye and with standard seven power binoculars, utilizing searchlights and special diffusely emitting light sources. Analysis of the results obtained with the naked eye in the daytime reveals absolutely no differences between thresholds obtained in the field and thresholds previously determined in the laboratory. Analysis of the other data obtained has not been completed to date.

A number of instruments were tested during the experiments to ascertain how accurately they permit determination of the coefficient of atmospheric scattering and absorption and hence prediction of the visual range of various objects, given object size, and contrast with its background. Good agreement was obtained with the various instruments used, and it is believed that when data analysis is complete, it will be possible to recommend a suitable instrument for practical use in making prediction of visual range.

These findings should render the practical application of laboratory visual detection data to certain field problems a great deal more feasible.

Several general methodological problems have been investigated which will assist in the design of future experiments to determine visual thresholds in the laboratory.

See Dr. Blackwell's report elsewhere in these minutes.

NR-143-151 Estimation of Speed and Angle of Approach of Aircraft

Contractor: Denison University, Granville, Ohio
Contract: N6ori-189, Task I (9/15/46 to 3/31/49)
Investigator: W. C. Biel

In the use of certain types of fire control equipment estimations of the speed of an aerial target must be made. Occasionally angles formed by the line of sight and the target fuselage must also be estimated.

In the first falf of 1945, a group of 20 commissioned Army anti-aircraft artillery officers were tested for the accuracy with which they could make these judgments. They were then given training in speed estimation by being told the "true" target speed for each course a short time after they had made their judgments. Following this, the observers were again tested in estimating speed and angle of approach to see if this type of training had any effect. During the experimental periods, courses varying in speeds, ranges, elevations, and direction were flown by the following planes: AT-11, PQ-14, B-25, B-26, P-47, and P-63. Criteria for true speeds and approach angles were obtained from computations based on continuously recorded azimuth and elevation angles (from M9 Director tracking) and slant range (SCR 584).

Under the present contract the speed estimations and angle estimations made by the observers are being compared separately with the criteria for the different types of planes, varying speeds of a particular plane, types of courses, before training, after training, etc.

Progress to 12/31/48: Because of delays in computation this project has been extended until 31 March 1949. Final analysis and preparation of the report are under way.

NR-143-153 Test of Color Vision

Contractor: University of Minnesota, Minneapolis, Minnesota
Contract: N6onr-246, Task I, (12/1/46 to 11/30/48)
Investigators: D. G. Paterson, M. A. Tinker

Under this project various color vision tests will be studied to determine (1) the amount of agreement in identifying color defective persons; (2) the reliability of these tests; and (3) the influence of other factors such as illumination, age, and socioeconomic status of subjects on these tests.

Progress to 12/31/48: This project has been terminated. No technical reports have been received.

NR-143-253 Response Mechanism of the Visual Threshold

Contractor: Indiana University, Bloomington, Indiana
Contract: N6onr-180, Task IV, (6/1/47 to 9/30/49)
Investigator: W. S. Verplanck

The measurement of sensory thresholds is the basic technique for investigating the sensory capacities of the human. The present program will examine each of the methods carefully, using standard instruments and stimuli, on a group of subjects who are young, healthy, of normal vision, and representative of service personnel. The variables to be investigated include inter-trial interval, spacing of steps, use of "vexir fehlen," conditions of reinforcement, shutter sounds, and "ready" signals.

It is expected that many of the difficulties encountered in making psychophysical measurements may be accounted for by the basic dynamics of behavior, and may be eliminated by using knowledge of these processes.

Progress to 12/31/48: Preliminary experiments have failed to verify one prediction of Hecht's quantum theory of the visual threshold, that the probability of response to any given stimulus in a long series of identical stimuli is independent of the response to the immediately preceding stimulus. Further experiments are under way and will be completed during the ensuing academic year.

NR-143-262 Peripheral Vision

Contractor: Johns Hopkins University, Baltimore, Maryland
Contract: N6onr-243, Task III, (2/1/47 to 6/30/49)
Investigator: F. N. Low

Under this project a study will be made of the effects of changing the illumination upon the peripheral vision of human subjects under both scotopic and photopic conditions. Special attention will be directed to the differences in apparent visibility which occur at dusk and dawn.

Progress to 12/31/48: A technical report, "The Effect of Suprathreshold Changes in Brightness on Form Perception," is being submitted for publication in the American Journal of Physiology." This project will terminate on 30 June 1949. A review of the literature and a bibliography are being prepared.

NR-143-292 Field Tests of Optical Equipment

Contractor: Indiana University, Bloomington, Indiana
Contract: N6onr-180, Task III, (3/1/47 to 6/30/49)
Investigator: W. S. Verplanck

Under this project the statistical analysis of the results of field tests of optical equipment conducted at the U. S. Submarine Base, New London, Connecticut, during 1945, will be completed. The objective is to determine the practical and relative values of various optical instruments under various conditions of visibility, visual performance, and Naval operations.

Progress to 12/31/48: The final report is being prepared, but the distribution will be limited because of its classification. The project has been extended to 30 June 1949 in order to provide extra time for the preparation of the report.

NR-143-325 Color Sense Measurement in Normal and Abnormal

Contractor: Cornell University, Ithaca, New York
Contract: N6onr-264, Task VII, (2/1/47 to 3/31/49)
Investigator: E. Murray

The purpose of this project is to secure a more sound empirical basis, through accumulated observations, for the science of color vision and its practical applications. The determination of the chromatic thresholds of normal and abnormal subjects will be made of critical points on the spectrum for the light adapted eye. Later, a distribution curve for each critical hue showing the range of high and low sensitivity and the median in normal and abnormal subjects will be established.

Progress to 12/31/48: A reprint of a technical report, "Mass-Testing of Color Vision,"

a Simplified and Accelerated Technique," is available. This project terminates on 31 March 1949.

NR-143-497 Study of Certain Aspects of Lookout Technique

Contractor: Yale University, New Haven, Connecticut
Contract: N7onr-288, Task V, (10/1/47 to 3/31/50)
Investigator: W. R. Miles

Eye movements of controlled groups will be photographed, under infra-red light, to determine the occurrence of suspected over-convergence during the detection of faint targets under low levels of illumination.

Different methods of using binoculars for the determination of the orientation of distant targets under low levels of outdoor illumination will be tested.

This project is supported by the Bureau of Medicine and Surgery under project number NM-003-033.

Progress to 12/31/48: Experiments are under way on studies of night lookout under blackout conditions and on target spotting with binoculars used continuously versus discontinuous use.

NR-143-638 Individual Constants of Luneberg's Metric of the Visual Space

Contractor: Columbia University, New York, New York
Contract: N6onr-27119 (11/1/48 - 10/31/49)
Investigator: L. H. Hardy

By mathematical analysis Dr. Rudolph Luneberg has established a correlation between physical space and the corresponding visual perception using non-Euclidian geometry. From this analysis, he derived a metric of visual space as a function of physical coordinates and two individual constants. It is proposed to conduct experiments in space perception which will provide empirically determined values for these constants. Such constants, when substituted in Luneberg's equations, will provide an empirical check on his theory.

Progress to 12/31/48: Preliminary experiments have shown that the so-called "Alley Experiment" cannot be used to test Luneberg's hypothesis. New experiments are being designed.

NR-143-669 Armed Forces-NRC Vision Committee
(Formerly NR-014-009)

Contractor: University of Michigan, Ann Arbor, Michigan
Contract: N5ori-116, Task I, (10/1/45 to 6/30/49)
Investigator: D. G. Marquis

The Armed Forces-National Research Council Vision Committee, formerly known as the Army-Navy-NRC Vision Committee provides consultative services in all aspects of the field of vision to the Army, Navy, and the Air Force upon request. By means of semi-annual meetings, the Committee brings together personnel from the Army, Navy, and Air Force research laboratories, the medical profession, university laboratories, and engineers to discuss visual problems of special interest to the military services. Both fundamental and applied research projects are reviewed and specific recommenda-

tions are made relative to research and development in the field of vision. This project is placed with the University of Michigan for the purpose of handling the administrative details of the Committee. The civilian members are appointed by the National Research Council. This project, formerly carried by the Physics Branch, under NR-014-009, has been transferred to the Psychophysiology Branch.

NR-143-826 Visual Space Perception

Contractor: Smith College, Northampton, Massachusetts
Contract: N8onr-75900 (1/1/49 to 12/31/49)
Investigator: J. J. Gibson

Under this project measured gradients of texture, perspective, size, bimocular disparity and motion will be presented to observers to determine whether or not an impression of depth results and whether such an impression, if found, varies concomitantly with the variation of the gradient.

NR-143-871 Photochemistry of Vision

Contractor: University of Michigan, Ann Arbor, Michigan
Contract: N6onr-23213 (10/1/48 to 9/30/49)
Investigator: James C. Peskin

Laboratory studies will be undertaken upon the chemical characteristics of the photosensitive visual pigments relative to the intensity of the adapting light and the effect of temperature upon the equilibrium concentration of visual purple. In addition, the effect of wavelength, intensity, duration of light adaptation upon the course of dark adaptation will be studied. Discrimination under various conditions of light and dark adaptation will also be studied.

Progress to 12/31/48: Equipment and materials have been procured, and work is beginning.

NR-143-909 Naval Research Advisory Panel for Psychophysiology

Contractor: Johns Hopkins University, Baltimore, Maryland
Contract: N8onr-79700 (1/1/49 to 6/30/49)
Investigator: H. K. Hartline

The Johns Hopkins University will provide an Advisory Panel for Psychophysiology acceptable to the Office of Naval Research and to have as its Chairman Dr. Haldane Keffer Hartline, Chairman of the Department of Biophysics. The University will provide consultative services, meeting place, office space for the Chairman, secretarial service and communication facilities. The University will arrange for transportation, subsistence, reimbursement and communication for the membership.

Naval Research Advisory Panel for Psychophysiology

H. Keffer Hartline, M. D. Chairman	Johnson Research Foundation University of Pennsylvania Philadelphia 4, Pennsylvania
Clarence H. Graham, Ph. D.	Department of Psychology Columbia University New York, N. Y.

George Wald, Ph. D.	Biological Laboratories Harvard University Cambridge 38, Massachusetts
E. Glen Wever, Ph. D.	Department of Psychology Princeton University Princeton, New Jersey
W. A. Munson	Bell Telephone Laboratories Murray Hill, New Jersey
Hallowell Davis, M. D.	Central Institute for the Deaf St. Louis, Missouri
Stacey Guild, Ph. D.	Johns Hopkins Hospital Baltimore, Maryland
Frank A. Geldard, Ph. D.	Department of Psychology University of Virginia Charlottesville, Virginia
Carl Pfaffman, Ph. D.	Department of Psychology Brown University Providence, Rhode Island

CONSULTANTS

Dr. Deane B. Judd	Photometry and Colorimetry Section National Bureau of Standards Washington, D. C.
Dr. Forrest L. Dimmick	Naval Medical Research Laboratory U. S. Submarine Base New London, Connecticut
Mr. Morris Leikind	Science & Technology Project Library of Congress Washington, D. C.

REHABILITATION OF VISION

NR-144-323 Research for Purpose of Improving Wearing Qualities of Contact Lenses

Contractor: H. J. Hoff, Washington, D. C.
Contract: N7onr-289, (2/1/47 to 1/31/49)
Investigator: H. J. Hoff

All contact lens research in the past 15 years has been aimed at delaying onset of haze in vision by using various aqueous solutions between the lens and eye. Results have been negative. A new contact lens is being designed to permit a rapid rate of flow of lacrimal fluid under the lens.

MISCELLANEOUS

NR-140-181 Development of Neuromuscular Mechanisms

Contractor: University of Kansas, Lawrence, Kansas
Contract: N6ori-164, Task VIII, (10/1/46 to 6/30/49)
Investigator: H. C. Tracy

The purpose of this project is to extend an earlier study on the development of embryonic behavior, using embryos of the Toad Fish, Opsanus Tau, a salt water teleost obtainable at Marine Biological Laboratory, Woods Hole, Massachusetts. It is proposed to study the relation of anatomical structure to observed behavior development particularly with regard to: (1) Relation of nervous system to first body movements; (2) histogenesis of muscle in relation to first movement; (3) relation of sensory nerves to first response to external stimuli; (4) development of eye and body movements on rotation, and their relation to nervous system; (5) histogenesis of sensory maculae in relation to reactions stated in (4); (6) test effects of motility and muscle histogenesis by removal of neural tube in earliest stages possible, and test effect on eye muscle developments by cutting eye muscle nerves; and (7) test effect of certain drugs on development of motility.

Progress to 12/31/48: Embryos of Opsanus Tau, collected at the Marine Biological Laboratory, Woods Hole, have been sectioned, stained and classified according to developing stages of behavior. Various staining techniques were used. Acetylcholine and cholinesterase in the embryo and the relationship between these substances and the development of behavior have been studied. The relationship of the earliest differentiation in the nervous system to the first movements in the embryo is being investigated, systematically.

NR-140-455 Influence of the Non-Auditory Labyrinth on the Effective Function of the Human Organism

Contractor: Tulane University, New Orleans, Louisiana
Contract: N7onr-434, Task I, (6/20/47 to 9/30/49)
Investigator: R. Brown

Under this project the research is divided into two parts: (1) A study of both normal persons and patients with nonfunctioning labyrinths in various tilting and rotating devices (including the human centrifuge) on the ground and, insofar as possible, in the air: (2) a study of the physiological aspects of (1) above, with particular attention to the nature and effects of conflicts and rivalry between the perceptions and the directives for action related to the labyrinths and those related to other sense organs, especially vision.

Progress to 12/31/48: Experimentation is continuing on the effect of rotation and gravity upon visual and auditory orientation of human subjects. A device for recording eye-movements during rotation has been constructed. Records will be taken simultaneously of the movements of one eye and the apparent motion, induced by vestibular nystagmus, of a stationary target seen by the other eye. The effects of adaptation to body tilt are being studied also. Four manuscript copies have been received of technical reports which have been submitted for publication in the Journal of Experimental Psychology: (1) "The Perception of the Postural Vertical: I. The Modification of Non-Labyrinthine Cues;" (2) "The Perception of the Postural Vertical: II. Visual Factors;" (3) The Perception of the Postural Vertical III. Adaptation Effects in Four Planes;" and (4) "The Perception of the Postural Vertical IV. The Visual Vertical as a Function of Centrifugal and Gravitational Factors."

A bibliography on vestibular functions and allied problems is being assembled. A critical summary and review of this literature is planned.

This project is supported jointly with the Bureau of Medicine and Surgery under Project No. NM-001-037 of the Research Division.

Navy Department

OFFICE OF NAVAL RESEARCH

MEDICAL SCIENCES DIVISION

Psychophysiology Branch

Technical Reports submitted by Contractors

1 December 1948

Anatomy, Physiology and Neuromuscular Functions of Vision

NR-141-017 University of Pennsylvania

Light and dark adaptation of single photoreceptor elements in the eye of limulus. Robb MacDonald and H. K. Hartline. J. Cell. & Comp. Physiol., 1947, 30: 225-254.

Responses to small changes of light intensity by the light-adapted photoreceptor. E. F. MacNichol (by invitation) and H. K. Hartline. Fed. Proc. Physiol. Soc. 1948, 7: #1.

Retinal action potentials of photoreceptor cells and the discharge of nerve impulses in their axones. H. K. Hartline. Fed. Proc. Physiol. Soc. 1948, 7: #1.

NR-141-022 Washington University

Tests for heterophoria. R. G. Scobee. Amer. J. Ophthal., 1947, 30, 436-451.

Relations between lateral heterophoria, prism vergence, and the near point of convergence. R. G. Scobee. Amer. J. Ophthal., 1948, 31, 427-440.

Size of line in the maddox-rod test. R. G. Scobee. Amer. J. Ophthal., 1948, 31, 697-699.

Anatomic factors in the etiology of heterotropia. R. G. Scobee. Amer. J. Ophthal., 1948, 31, 781-795.

A problem in vision research. Richard G. Scobee. Research Reviews, Office of Naval Research, 1948, 15 June.

Some practical points about the recession operation. R. G. Scobee.

Intermittent exotropia. R. G. Scobee.

Anatomy, Physiology and Neuromuscular Functions of Vision (cont'd)

NR-141-022 Washington University

The non-surgical treatment of heterotropia. R. G. Scobee.

Degrees of correction per millimeter of surgery. R. G. Scobee.

The fascia of the orbit. R. G. Scobee. Am. J. Ophthalmology, Vol. 31, No. 12, Dec. 48.

Post-operative hypertropia. R. G. Scobee. Am. J. Ophthalmology, Vol. 31, No. 11, Nov. 1948.

NR-141-277 Harvard University

The sensitivity of the human eye to infra-red radiation. George Wald, J. Opt. Soc. Amer., 1947, 37, 546-554.

Interconversions of retinene and vitamin A in vitro. George Wald. Fed. Proc., 1948, 7, No. 1.

Galloxanthin, a carotenoid from chicken retina. George Wald. Jnl. Gen. Physiol., 1948, 31, 377-383.

The synthesis from vitamin A_1 of retinene$_1$ and of a new 545 mu-chromogen yielding light-sensitive products. George Wald. Jnl. Gen. Physiol., 1948, 31, 489-504.

"Selig Hecht", by George Wald (1892-1947) The Journal of General Physiology, Sept 20, 1948, Vol. 32, No. 1, pp. 1-16.

"The Photochemistry of Vision" Technical Report No. 4.

"The Reduction of Retinene$_1$ to Vitamin A_1 in vitro", by G. Wald and R. Hubbard. Technical Report No. 6

"The Enzymic Reduction of the Retinenes to the Vitamins A," by G. Wald, Technical Report No. 7.

"Interplay of Light and Heat in Bleaching Rhodopsin" by R. C. C. St. George introduced by G. Wald. Technical Report No. 8.

"The Enzymic Reduction of the Retinenes to the Vitamins A", by G. Wald. Technical Report No. 9

"Crustacyanin, the blue carotenoidprotein of the lobster shell." G. Wald, Neal Nathanson, W. P. Jencks and Elizabeth Tarr. Tech. Report

Physiological Optics

NR-142-404 Columbia University

Stereoscopic acuity for various levels of illumination. Mueller, C. G. and Lloyd, V. V. Proc. Nat. Acad. Sci., Wash., 1948, 34, 223-227.

Physiological Optics (cont'd.)

NR-142-404 Columbia University

Visual perception. Graham, C. H.

The magnitude of the pubfrish stereophenomenon as a function of level of illumination and intensity differences. Lit, A.

Some temporal aspects of figural after-affects. Hammer, E. R.

Factors influencing vernier acuity. I. Intensity and exposure time. II. Wave length. Baker, K. E.

Monocular movement parallax thresholds as functions of field size, field position and speed of stimulus movement. Zegers, R. T.

The course of foveal light adaptation measured by the threshold intensity increment. Baker. H. D.

Precision of stereoscopic settings as influenced by distance of target from a fiducial line. Graham, C. II., Riggs, L. A., Mueller, C. G., and Solomon, R. L.

Stereoscopic settings with reticles providing multiple reference ranges: the space perception of repeating patterns. Graham, C. H., Hammer, E. R., Mueller, R. D., and Mote, F. A.

Monocular Movement Parallax Thresholds as Functions of Field Size, Field Poition, and Speed of Stimulus Movement. Richard T., Zegers, S. J. The Journal of Psychology 1948, 26, 477-498.

Factors Influencing Thresholds for Monocular Movement Parallax. C. H. Graham, K. E. Baker, Maressa Hecht, and V. V. Lloyd. Journal of Experimental Psychology, Vol. 38, No. 3, June 1948.

Numerical transformations in the analysis of experimental data. C. G. Mueller. (Tech. Report)

Precision of stereoscopic settings as influenced by distance of target from a fiducial line. by Graham, Riggs, Mueller, and Solomon. J. Psychol. 1949, 27, 203-207.

Stereoscopic settings with reticles providing multiple reference ranges: the space perception of repeating patterns. J. Psychol., 1949, 27, 209-216.

Perceptual Functions of Vision

NR-143-106 University of Michigan

The relation between visual sensitivity and viewing distance. H. R. Blackwell.

An automatic presentation, recording and analysis device for vision experimentation. H. R. Blackwell, and B. S. Pritchard.

Perceptual Functions of Vision (cont'd)

NR-143-106 University of Michigan

A sutdy of methods of visual threshold determination. H. R. Blackwell.

The influence of psychophysical procedure upon visual response data. H. R. Blackwell.

NR-143-262 Johns Hopkins University

Peripheral visual acuity of 55 subjects under conditions of flash presentation. F. N. Low. Amer. J. Physiol., 1947, 151, 319-324.

The effect of changing brightness on peripheral form perception. F. N. Low.

The effect of suprathreshold changes in brightness on form perception. F. N. Low.

NR-143-325 Cornell University

Mass color vision testing. Elsie Murray. To be published, Amer. J. Psychol.

Color vision tests. Elsie Murray. To be published, Handbook of Medical Physics, Cleveland Clinic Foundation.

Rehabilitation of Vision

NR-144-080 Cornell University

Facial Vision: Perception of obstacles by the deaf-blind. Philip Worchel and K. M. Dallenbach. Amer. J. of Psychol., 1947, 60, 502-553.

The vestibular sensitivity of deaf-blind subjects. P. Worchel and K. M. Dallenbach. Amer. J. Psychol., 1948, pp. 502-553.

REPORT OF SUBCOMMITTEE ON VISUAL STANDARDS

David Freeman, (Acting for the Chairman)
Washington University

The Subcommittee on Visual Standards met in Washington D. C. on the 17th and 18th of February 1949. The following persons were present:

Dr. Richard G. Scobee, chairman
Col. Victor A. Byrnes
Dr. B. J. Wolpaw
Dr. Louise Sloan Rowland
Dr. William Rowland
Dr. John L. Matthews
Dr. Earl Green
Dr. N. C. Kephart
Dr. Henry Imus
Dr. David M. Freeman
Maj. Robert A. Patterson
Col. Austin Lowery
Mr. M. H. Salzman
Dr. William Berry

The first item considered was a request from the Photogrammetry Section, Chart Construction Division, U. S. Navy Hydrographic Office that the Vision Committee make suggestions and recommendations which would lead to better selection and classification of personnel which the Photogrammetry Section plans to employ in the near future. The section is currently undergoing an expansion program and would like to improve the present method of selection and training of applicants in order to minimize training costs and time, and to improve efficiency and personnel morale. In addition, the committee was asked to make suggestions for improvement of the presently used equipment and any other pertinent factors they deem advisable.

Mr. M. H. Salzman of the Photogrammetry Section stated the problem of the section and went on to explain the type of stereoscopic equipment used in order that the subcommittee might have more background of a practical sort before any recommendations were made.

There are three stereoscopic devices which are used by the Photogrammetry Section. These are, (1) The K.E.K. Stereoscopic Plotter (2) The Aero Multiplex and, (3) The Zeiss Stereoplanigraph.

The first two instruments are the most frequently used and will pose the greatest problem.

The K.E.K. Stereoscopic Plotter is a device to view two aerial photographs stereoscopically with adjustments provided so that the photographs may be oriented relatively with respect to X and Y parallax and a floating dot system so that there may be absolute orientation in the plane of depth. One looks into the device thru a binocular eyepiece and, by means of a tilted mirror for each eye, views two photographs stereoscopically. A black dot is interposed into each line of vision so that when one looks at a certain level on the stereoscopic picture he may see a single dot floating above or below the plane of the photograph or he may see two dots rather than a single one. If one now raises or lowers the stereoscopic photographs and keeps his attention on the photograph,

a position may be found where the single dot seems to be at the same level as the area of regard. If, for example, he moves the stereophotos carefully and keeps the floating dot on the level of the point of interest, relative elevations can be measured and recorded automatically. If two or three points in the area are known, absolute elevations can be determined. This is the most frequently used instrument and has to be operated from the standing position, the operator bending his head forward to look into the binocular eyepiece which is set in the horizontal plane.

The aero multiplex is a projector system which uses complementary red and green colors in projecting the images from two stereoscopic "dipositives" onto a small round plating. One views the projected images through colored filters which are practically mutually exclusive. One projector is fitted with a red color filter and the other with a blue-green filter and are so arranged that the images are projected at the same point on the plot in space. When one wears a red filter over one eye and a blue-green filter over the other, stereopsis is achieved. Again a "floating dot" system is used to measure relative elevations just as in the K.E.K. In operating this device one bends over a table and moves the plating about manually moving the dot as necessary to keep it on the level of the area of interest.

The Stereoplanigraph is a stereoscopic device again used to measure and record relative elevations from aerial plots. It is quite a complex stereoscopic device which Mr. Salzman did not explain. There is only one such device available in the photogrammetry section and we are told there will be no real problem as far as this instrument is concerned since there is only one available for use and very few people are to be trained to use it. It is said to be more accurate than the other more commonly used devices.

Several of the problems which were evident were discussed: The relation of image distortion and interpupillary distance in using the K.E.K. which has a fixed I.P.D. of 62mm; the advisability of color testing trainees who are to use the Aero Multiplex; the advisability of testing phorias, visual acuity, vernier acuity and stereoscopic ability before the training period is begun. This discussion served largely to further orient the group in the problems relative to using stereoscopic instruments.

In the afternoon, the group visited the Photogrammetry Section of the Navy Hydrographic Office in Suitland, Maryland. The instruments previously described were demonstrated and members of the Subcommittee were given an opportunity to examine them and ask questions. A brief conference was then held with members of the Section to discuss their problems. Dr. Scobee asked if color rivalry had been a problem to operators of the multiplex. Mr. McCurdy of the Section replied that by controlling the intensity of each color, color rivalry was not a great problem. A question was asked about fatigue and visual complaints by those who operate the devices, but no study of the problem had been made, and the question could not be answered adequately. The age range of the operators was not known exactly, but was estimated to be between 25 and 45 years. Col. Byrnes suggested that red and blue-green lights used in the multiplex might be a source of fatigue since each color required a different amount of accommodation for accurate retinal focusing. Dr. Wolpaw said that he believed the present operators should be examined and refracted, i. e. both those who were successful operators and those who had failed to do satisfactory work, in order to find out something about the visual requirements of a successful operator. It was pointed out by Mr. McCurdy that many who could operate one device frequently were not able to operate another successfully and that he

believed that incentive and interest were paramount factors. Dr. Matthews suggested that a possible method of selection of trainees might be to examine prospective operators and to refract them, then give them a work test on the K.E.K.

There was some discussion about instrument design and postural fatigue, especially as concerned the K.E.K. Sterescopic Plotter, but members of the Section did not believe these to be particularly difficult problems since rarely did an operator stand at the K.E.K. more than two to three hours.

Near the conclusion of this period Dr. Scobee suggested that each member of the Subcommittee consider specific proposals for selection and training of personnel.

The Subcommittee met the following day and more specific proposals for selection and training of personnel for the Photogrammetry Section of the Navy Hydrographic Office were considered. Each member was asked for his recommendations. The following is a summary of the suggested recommendations which the Subcommittee believes are most applicable to the problem. They are listed under five headings:

1. Examine the present employees who operate the stereoscopic devices used, examining also those at the Army Map Service, Forestry Service, and elsewhere where similar instruments are used if found to be practicable. The examination should include the following:
   a. Visual profile as determined by the Orthorater.
   b. Manifest refraction.
   c. Performance rating of the present employees as to satisfactory or unsatisfactory on each stereoscopic device used, rating to be made by a minimum of two and preferably three people.

2. Examination of Applicants. The examination should include:
   a. Visual profile on the Orthorater
   b. Clinical ophthalmologic examination to include points listed:
      Vision with and without correction, each eye and binocularly.
      Muscle balance (Maddox rod at 20' and 13'').
      Prism vergence studies at 20' and 13''.
      Near point of accommodation (with correction if worn).
      Near point of convergence.
      Interpupillary distance (NDRC interpupillometer).
      Complete external and internal examination.
      Cycloplegic refraction, or manifest if cycloplegic is not possible.
   c. Prescription of glasses if deemed advisable by the examiner, or if necessary to meet minimum visual requirements as listed below.

3. Minimum visual requirements for acceptance for training:
   a. Must have at least 20/30 corrected vision in each eye and should have not more than two line difference in acuity, i. e. 20/20 and 20/30 or 20.25 and 20/15.
   b. Must have binocular vision including stereopsis.

4. Training Period.
   If an applicant is acceptable visually he should be given a period of training designed not only to train the person in the type of work he is to do but also to determine his aptitude and possibilities as an operator.

This training period should be sufficiently long to give the trainee an adequate trial before he is rejected or transferred to another type of work. This trial period should be at least two weeks, or longer if deemed advisable.

5. Additional Recommendations:

The following suggestions are submitted with a view of improving instrument design, improving efficiency, and facilitating selection of new personnel:

a. That a study be made of the presently used color filters in the Aero Multiplex with a view of adding spherical correction to compensate for the chromatic interval induced between the eyes with an attempt, also, to produce a set or pair of more completely mutually exclusive filters. A study of polaroid filters is suggested to see if they might be even more desirable than color filters because of the absence of color.

b. That a study be made to improve the working position of the operator of the K.E.K. Stereoscopic Plotter and also to study the present illumination on the photographs and possibly improving it.

c. That Mr. Salzman of the Section be given opportunity to acquire further ophthalmic background by observing at the Eye Clinic at Walter Reed Hospital, The Naval Dispensaries, and elsewhere if it is deemed advisable.

With the above information available, it should be possible to set up more reliable criteria for selection of personnel than those now used.

The group then turned its attention to a consideration of the Air Surgeon's request for advice concerning a visual screening device. Dr. Scobee repeated that a renewal of a previous request had been made and that information on a visual screening device is required. The request stated that if an instrument is available, and if it is reasonably satisfactory, a recommendation should be made in spite of known imperfections. Dr. Louise Sloan then gave a preliminary report on her work in redesigning the test slides on the orthorater and sight-screener.

There was some discussion of her work and results, and specific recommendations were then prepared concerning the selection of a screening device. The following recommendations concerning the selection and design of a visual screening device have been agreed upon by the Subcommittee:

RECOMMENDATIONS FOR A VISUAL SCREENING DEVICE

The Subcommittee on Visual Standards of the Armed Forces-NRC Vision Committee met in Washington on February 17 and 18, 1949. One item studied was a request from the Air Surgeon for an immediate opinion on the subject of the adoption of a visual screening device for use by the Air Force at this time. It is realized that various studies now in progress may result in future recommendations for alteration of presently available instruments. Dr. Louise Sloan Rowland of the Wilmer Institute, Johns Hopkins, Baltimore, has been studying the problem under contract N6onr-243 with the Office of Naval Research. On the basis of her studies to date as well as on previous studies, the following

recommendations are made, following a detailed consideration of two of the visual screening devices now available commercially.

THE ORTHORATER (Bausch & Lomb)

Heterophoria

1. The tests of heterophoria should be placed first in order of testing at the near distance as well as at far. The reason for this is the known effect of certain binocular visual tasks requiring fusion upon heterophoria readings when the former are performed just prior to heterophoria determinations.

2. The range of vertical heterophoria tested should be increased from the present 1.5 prism diopters to 2.0 prism diopters.

3. The red dots seen by the left eye in the heterophoria test should be changed to white dots. This is suggested because the human eye is hepermetropic to the extent of at least 0.5 diopter for the color red. While this may be of no practical importance, it seems better to eliminate a possible source of disagreement between different tests.

4. It appears advisable to have a demonstrator slide for use in explaining the vertical heterophoria test to examinees before administering the test. This is needed in order to eliminate confusion about what is meant by "aligning the row of dots with the stair-steps."

5. There is a well recognized variation in measurements of vertical heterophoria. This variation was encountered by Dr. L. S. Rowland in her studies but the number of subjects with large vertical imbalances is not sufficient at the present time to justify any conclusions as to the cause of this variation in her studies. Previous studies have shown that the Orthorater is superior to other visual screening devices with respect to vertical phoria measurements because it has the highest variance attributable to vertical phoria and the lowest attributable to other factors. In view of these observations, there is no valid reason for suggesting changes except in the range of the present vertical phoria test employed in the Orthorater.

6. By proper selection, it is possible to secure satisfactory agreement between lateral phoria scales on both visual screening devices and clinical tests. There is, therefore, no reason to suggest any changes in the lateral phoria test on the Orthorater at this time except to calibrate the scale in intervals of one prism diopter at both near and far. This is particularly true since a previous study has shown the Orthorater to have the highest variance attributable to lateral phoria of any of the other visual screening devices now available commercially.

Visual Acuity

1. It is known that the variance attributable to resolution is essentially the same on the machine tests as on clinical tests. Therefore there is no reason to suggest a change at this time in the type of visual acuity test employed in the Orthorater, with the following few exceptions:

a. At the far distance, the test range should be from 20/400 to 20/13.3 inclusive. The tests need be monocular only and would be performed with the untested eye occluded. To provide more than one target at critical levels necessitates two slides of the checkerboard type devoted to acuity for the far test instead of the present single slide.

b. For the near test, the range can be smaller. A range equiavalent to 20/50 through 20/13.3 would be sufficient. A range of 20/50, 20/40, 20/30, and 20/20 with ten characters in each line could be placed on a single slide. The near test would also be done monocularly.

2. The present type of checkerboard test target is deemed adequate although studies of other types of test targets are being conducted. It is entirely possible that a recommendation for a change in target type might be made at some later date when Dr. L. S. Rowland's studies are concluded.

Depth Perception

1. The present demonstration squares in the test for stereopsis are not suitable because the disparity is so great that many subjects have difficulty in appreciating it at all. To avoid the use of an external model, it is recommended that the demonstration line be changed to a level of disparity very close to that of line A in the test itself. Three demonstration lines with varying levels of disparity would be even better than a single one.

2. Dr. L. S. Rowland's study as well as others have shown that roughly 30% of examinees will fail the test of stereopsis in the Orthorater on the first administration. Many who fail this test the first time it is given can pass it on a subsequent trial. To avoid "false failures" in mass screening, then, it is suggested that an adjunct test of true depth (either the Howard-Dolman or the Verhoeff) rather than one of stereoscopic depth involving retinal disparity only be administered to those failing the latter test when first administered. All examinees failing the adjunct test also could be considered unfit for any task demanding good depth perception.

Color Vision

The present test slide for color vision is unsatisfactory. On the basis of present knowledge about color vision screening tests, it is very unlikely that any suitable screening test employing pseudo-isochromatic plates could ever be presented on a single slide; it is probable that a minimum of ten slides or charts would always be required. The technical difficulties in the reproduction of pseudo-isochromatic plates on transparancies are numerous. In view of these facts, it is recommended that the present Orthorater test of color vision be omitted entirely and that color vision screening be accomplished as it is at the present time in the Air Force by means of pseudo-isochromatic charts illuminated as now specified in regulations.

THE SIGHT SCREENER (The American Optical Co.)

Heterophoria

1. Comments made on lateral phoria in the Orthorater section are equally applicable here.

2. The vertical phoria test needs modification. The variance attributable to vertical phoria on this instrument is very low (0.24) and should be higher. It is recommended that two parallel horizontal lines be substituted for the present single horizontal line, as has been suggested by the American Optical Company. The number of dots in the vertical row should also be increased from seven to nine. This would serve to provide easier reading of the test and at the same time increase the range of vertical phoria tested.

3. There seems to be no need for a demonstrator slide employed outside the machine in the case of the phoria tests.

Visual Acuity

1. Comments made under this same heading in the Orthorater section are applicable here.

2. Dr. L. S. Rowland is studying a Landolt ring test target and has a slide covering a suitable range (20/400 to 20/20). It appears to be as satisfactory as any other type of test target. Unless the 20/400 letters are omitted, the Sight Screener does not provide space for a greater number than four test characters at levels below 20/40. The Orthorater standard slide, however, has only one test character at each level.

Depth Perception

1. A demonstrator slide for use outside the machine is supplied for this test with the Sight Screener and apparently fulfills its task very well. It might not even be needed, however, if a demonstration series were included in the test itself.

2. The standard stereoscopic test is not as effective as the Orthorater test and has the same disadvantages. An adjunct test probably will be required for either machine.

3. The variance attributable to depth perception on the Orthorater is higher (0.42) than on the Sight Screener (0.14) as shown in a previous study.

Color Vision

The Sight Screener has no test of color vision.

DISCUSSION

It is realized that the figures on variances mentioned came from studies in which there were obvious defects in the slides used in both the Orthorater and the Sight Screener. If these had been remedied, the figures might have been somewhat different.

The Orthorater is a lens-prism stereoscope while the Sight Screener is a polaroid stereoscope. Both tests are near tests and add lenses and prisms to simulate infinity. The polaroid principle in the Sight Screener necessitates the use of test targets of low contrast. The drum arrangement of the Orthorater

provides more space for test target than does the single flat slide of the Sight Screener.

Positive malingering is recognized as an extremely important air force problem. Many applicants are anxious to appear better than they may actually be. Passing marks in a screening test will quickly become known by word of mouth to examinees yet to be tested. For this reason, it is apparent that a satisfactory screening device should have a minimum of two and preferably three various forms of certain tests, particularly for phoria. At least two and preferably three slides having different readings for the normal range should be available. This could be accomplished either by changing slides or changing drums. For example, orthophoria might be at 8 on one lateral phoria slide and at 5 on another; the same variation should be available in the vertical phoria test.

CONCLUSIONS

The conclusions to be stated here are based upon a careful consideration of Dr. L. S. Rowland's incompleted project and upon previously conducted studies on visual screening devices. It has already been shown that the machine tests are as reliable or more reliable than corresponding clinical tests. The variances attributable to the different factors being measured are higher in both the Orthorater and the Sight Screener than in the Telebinocular, and the Orthorater provides better measures in a majority of instances.

With modifications not too difficult to make in the Orthorater, such as (1) additions to the visual acuity test, (2) elimination of the color vision test, (3) arrangement of test order such that phoria is tested first at far as well as at near, (4) arrangement of the lateral phoria scale in units of one prism diopter at both near and far, (5) reduction of disparity in the demonstration squares in the test of stereopsis, and (6) availability of different phoria test slides, this instrument should be the one selected for use by the Air Force.

Acceptance of the above suggested changes would leave space available in the instrument for the addition of other slides if and when a need became apparent or when such slides were desirable for purposes of further study in the field. The construction of the Orthorater is such that the substitution of new slides or revised ones is a relatively simple matter and could be performed by the operator wherever the instrument happened to be located.

DISCUSSION:

Dr. Scobee discussed the photogrammetric operator selection program. He stated that since no one knows what the visual requirements are for using the stereoscopic mapping equipment, it is his belief that large numbers of persons now utilizing the equipment should be tested and a job analysis conducted on the basis of performance criteria. Certain obvious visual requirements could be set up in advance of such a job analysis. For example, if the visual acuity in one eye is more than two lines different from the other eye, then rejection could be made *a priori*.

Dr. Scobee pointed out that a study of the present mapping operators would represent a selected population since failures on the mapping equipment would

have been rejected from the sample. He pointed out that the preliminary information obtained from the testing of operators now in service could only yield hints as to the real visual requirements. These hints could be utilized in a second study to be made with new trainees. With the new trainee population, unsuccessful operators would be uncovered and the visual requirements therefore specified with greater validity.

Dr. Imus reported the testing program which had been undertaken on the steromapping operators as a consequence of the recommendations made by the Subcommittee. Orthorater profiles were obtained on each of the operators available for study, utilizing the Orthorater installed at the Naval Gun Factory. The Office of Naval Research wrote a contract to provide for the manifest refraction of all steromapping operators. This information should provide the preliminary hints as to visual requirements suggested by the Subcommittee.

(The discussion was then directed toward the recommendation for a visual screening device, submitted by the Subcommittee.)

Colonel Byrnes expressed his belief that the visual screening device should clearly not be expected to supplant the Air Force ophthalmological examination now in use. Visual acuity, far and near, can however be tested satisfactorily, apparently, on the machine screening device.

Colonel Byrnes suggested that the entire philosophy of the visual screening device needs to be re-examined in terms of the Air Force requirements. He suggested that if accommodation and far-vision tests were utilized, near-vision tests could be eliminated. He suggested the importance of such factors as fatigue and anoxia, whose importance lies in their influence upon the patient's ability to overcome phoria. Colonel Byrnes mentioned particularly the possibility that prone flying would be introduced, which results in bad vertical phoria for those with orthophoria under normal conditions.

Dr. Scobee commented that the ideal man for prone flying would possess 12 diopters of esophoria and good fusional ability. Prone flying requires distorted vertical regard which introduces approximately 12 diopters of exophoria to a pilot with orthophoria.

Dr. Sloan asked whether Colonel Byrnes believed the inclusion of a 20/400 character is necessary in the visual screening device. She commented that the 20/400 character consumes half the visual acuity slide.

Colonel Byrnes replied that a 20/400 character is not necessary under the present conditions, but that under total mobilization, a very wide spread in acuity range would be encountered.

Dr. Sloan suggested that a 20/400 character could be mounted outside the machine and rotated by hand to simplify the design of the visual acuity slide.

Colonel Byrnes replied that if it were possible, it would be desirable to leave 20/400 character inside the machine.

Dr. Sells suggested that the screening device should not be expected to give complete examination of examinees over the entire range of visual acuity. He stated his belief that the extreme portions of the distribution could be ignored in the screening device and investigated at greater lengths by ophthalmological examination.

Dr. Sloan stated her belief that Dr. Sells had "put his finger" on the critical point of the discussion. She asked Colonel Byrnes whether the Air Force was not expecting the screening device to be more than a screener, but instead to provide the final examination of all candidates.

Colonel Byrnes agreed that the Air Force would like the screening device to give the final test of those functions which it set out to measure. Under these circumstances, a man's visual acuity could be noted on his admission to the service and it would not have to be tested again.

Dr. Scobee reminded Colonel Byrnes that the recommendations of the Subcommittee were based upon the desire for a visual screening device only. He also emphasized that the recommendations implied only that the screening device was the best of several available and not necessarily the best possible.

Dr. Rowland questioned whether the Air Force would indeed wish to make a single measure of visual acuity and use it throughout a man's service since this means he would not be re-examined for years.

After discussion, the Vision Committee approved the recommendations regarding a visual screening device prepared by the Subcommittee, and requested the Executive Secretary to transmit the recommendations to the Air Surgeon.

ANOMALIES OF THE OCULOROTARY MUSCLES

Richard G. Scobee, M.D.
Washington University

The movements of man's two eyes are controlled by six muscles on each globe -- a total of twelve in all. Each of the six muscles on an eye has one direction in which it moves the eye with maximum efficiency. As a result of the fact that there are six muscles, each working most efficiently in one direction, there are what are known as six cardinal directions of gaze. These six directions are up and right, straight right, down and right, up and left, straight left, and down and left. If an eye is to move straight upward, the movement is accomplished by a synergistic action of two muscles -- one whose primary action is moving the eye up and right and the other whose action is to move the eye up and left. It is thus that we can look in any desired direction at will by utilizing various synergistic combinations of these six muscles. It is easy to understand the movements of a single eye. Complications arise from the fact that we have two eyes and that these two eyes must move in exactly the same direction at the same time and by approximately the same amount if binocular single vision is to be maintained.

An extremely delicate and complex system of integrated nervous controls is required to produce the movements of our eyes called for during most of our waking hours. The more delicate the controlling mechanism, the more easily it can be thrown out of balance by minor influences. The control mechanism is also known as the fusion mechanism. The fusion mechanism can and does compensate for many of the disturbing factors which might otherwise disrupt binocular vision, although this is often accomplished only with the expenditure of extra effort. A constant strain on the fusion mechanism results in the symptoms of asthenopia or eye-strain. A one-eyed man never has headaches because of eyestrain. The symptoms of eyestrain come from man's attempt to use his two eyes together as a team.

With the passage of time and the increase of our knowledge of the binocular neuromuscular mechanism, we have been able to identify, and to a certain extent catalogue, a number of the factors which affect the position of the eyes with respect to each other and to the position of each in its orbit. Other factors are known to exist because their effects are obvious, but they have not yet been identified. This report is concerned with one of these factors which was identified many years ago but whose mode of action has only recently been understood to any great extent.

Under normal conditions, when we gaze at an object located at a distance of, say, one mile, the visual axes of the two eyes are practically parallel. If there is no tendency whatever for the eyes to deviate away from this position of essential parallelism, the individual is said to be orthophoric--he has orthophoria. If there is some tendency of the eyes to deviate from parallelism, some tendency which is kept in check by the fusion mechanism so that no actual deviation occurs, there is heterophoria. If the heterophoria is large enough in amount, an excessive strain is thrown upon the fusion mechanism and symptoms are produced. If the tendency toward deviation of the eyes is so great that it cannot be held in check by the fusion mechanism, then an actual manifest deviation occurs, fusion is disrupted, and heterotropia is said to be present. Heterophoria is a tendency of the eyes to deviate, a tendency which is held in check by the fusion mechanism. Heterotropia is an actual deviation which occurs

when fusion is unable to hold the deviation-tendency in check. Heterophoria and heterotropia are really different degrees of the same thing -- a tendency of the eyes to deviate at the expense of binocular single vision.

Until fairly recently, heterophoria was thought to be mostly innervational, or nervous in origin, and many reflexes which played upon the binocular mechanism were listed as possible causes of heterophoria. Anatomic factors were recognized as playing a relatively small and unimportant role in such deviations -- whether phoria or tropia.

From a study first of the so called "normal," both in the dissecting room and on the operating table, it became possible not only to recognize but to classify certain types of anomalies which are found in patients with either heterophoria or heterotropia a large percentage of the time. These anomalies are of four types: (1) anomalies of the check ligaments, (2) anomalies of the intermuscular membrane, (3) insertional anomalies, and (4) muscle slips. These have been described in some detail in previous publications (Am. J. Ophthalmology 31:781, 1948; Am. J. Ophthalmology 31:1539, 1948) and will not be considered further here.

The effect of such anomalies is generally to act as secondary attachments for the oculorotary muscles. These secondary attachments do not increase the efficiency with which their muscle contracts; instead, they prevent adequate relaxation of that muscle when its antagonist contracts.

The six muscles that move each eye are paired in antagonistic teams which normally balance each other. Agonist and antagonist are so innervated that when one contracts, the other relaxes and this is Sherrington's law of reciprocal innervation. If anatomic anomalies act to prevent adequate and proper relaxation of the antagonist when an agonist is contracting, then that agonist cannot contract maximally because of the mechanical obstacle on the antagonist. The delicate innervational control of the eyes is upset and certain imbalances result which strain the fusion mechanism. Thus may anatomic anomalies play a role in the production of heterophoria. We have already stated that heterotropia and heterophoria differ from each other only in degree. If the anatomic factors mentioned are sufficient obstacles to throw a severe strain on the fusion mechanism, an added strain from any other source (such as refractive error working through the accommodation-convergence reflex) may be sufficient to disrupt fusion completely and the result is a tropia. It is thus that anatomic anomalies may play a causative role in the production of heterophoria and an underlying role although rarely acting as precipitating factors in the production of heterotropia.

(Note: This is an abstract of the presentation. For details and illustrations, the reader is referred to the two references given.)

DISCUSSION:

Dr. Sells asked how the information on the incidence of tropias was obtained.

Dr. Scobee replied that the tropia information was obtained by the case history method. He admitted that the case history method is notoriously unreliable. Dr. Scobee expressed the opinion, however, that the relationship between duration of labor and time of emergence of tropia really exists because mothers hesitate to acknowledge tropia at birth. This reluctance would affect the data in the opposite direction to the effect noted.

CHAINS OF OCULAR AND SENSO-MOTOR LATENCIES OF LOWER AND HIGHER ORDER

by
H. Strughold, M. D., Ph.D.
School of Aviation Medicine, Randolph Field

In times of such rapid development in science and in engineering as we have seen within the last fifty years, it is of special importance to look back into the past occasionally and take time to trace a prospective problem back to the day when it first appears in the related literature. Such retrospection would not mean a retrogression, but rather a progression in science. Frequently, we find old discoveries of great value to present-day scientists though soon after their discovery they sank into oblivion. The reason for this was chiefly that they were not coordinated with other similar findings, or that at the time of their discovery the possibility of their useful application did not exist. Many findings, however, which have passed the years vegetating, have suddenly become of great interest, having numerous applications because of two great inventions: the airplane and the rocket and its further development. But to utilize properly these findings published here and there, it is important to bring them into a clear logical system, and to relate them to the present state of development. This is a task of a theoretical combinative physiology. In this connection I shall discuss the ocular sensory and senso-motor latent periods. To have the privilege of doing this in the presence of this distinguished committee is a great honor and a pleasure for me.

The simplest act of vision is performed when the image of a distant object is caught by the fovea; for in this case the latent period for obtaining distinct perception is the shortest. This period is composed of the latency of the retina, of the conduction time in the centripetal pathways, and of the time required to attain a certain excitation level in the perceptor of the cerebral cortex. This latent period of the foveal perception consumes, according to the methods of Helmholz, 1860; Exner, 1868; Pieron, 1910; Monje, 1930; and to those of Hazelhoff, 1923; and of Froehlich, 1929; and of Pulfrich, 1922, minimally 35 milliseconds. The electrophysiological investigations by Adrian and Matthews, 1927, and recently by Noell (personal communication), coincide very well with this finding. Noell (School of Aviation Medicine, Randolph Field, Texas) found that with strong light stimuli the first impulses can be evidenced in the optical nerve of rabbits after 15 milliseconds, and in the upper layers of the cortex after 23 milliseconds. M. Monnier and R. L. Jeanneret, 1947, found 45 milliseconds for the retinal latent period and 124 milliseconds for the post-retinal or central time. Without going further into details in how much the latent period of foveal perception depends upon the intensity of the stimulus and upon the wave length of the light, we can say that this period--under the normal light conditions of daily life--is below rather than above one-twentieth of a second.

Under the same conditions the extrafoveal perceptual latent period is above rather than below one-twentieth of a second. That the extrafoveal latency is longer than the foveal one has been demonstrated by the direct measurement of Froehlich. It can also be concluded from measurements of simple reaction times in response to stimulit applied to the various regions of the retina (von Kries and Auerbach, 1877; Wirth, 1927; Poffendorfer and Weiker). (Figure 1.)

The existence of this perceptual latent time indicates that our perception lags behind the environmental events. In other words, there exists an anisochronia between them. The clockwork of our senses is one-twentieth to one-tenth of a second late. In the movements of our daily life this physiological lag is insignificant. During flight at supersonic speeds, however, a considerable distance is covered within this period of time.

For instance, at a Mach number of 3 this distance is about 100 meters. This distance is--so to speak--swallowed by the latent physiological process which precedes the perception. It practically does not exist. We may call it "blind distance" or "kinetic distance scotoma" or "non-perceptual interval."

The latent time of visual perception is the first and simplest, and is an ever present element in all kinds of reaction times. But visual perception can also be of a complex nature which is often the case if the image of an object falls upon the periphery of the retina.

In this case the object is not distinctly perceived. In order to insure distinct vision, it must be caught by the fovea and pictured there distinctly. To this end various processes come into play between extra-foveal and foveal perception. They are as is generally known:

1. The saccadic conjugate movement of the eye between fixation.
2. Convergence.
3. Accommodation.
4. Pupillary reaction.

Hence the visual act, beginning with the appearance of the object on the peripheral retina and proceeding to the moment of distinct foveal vision, represents a time-consuming chain of successively and/or simultaneously occurring links--a <u>chain process</u>, still more important in high speed than the simple foveal perception.

The main subject of this discussion is to investigate this entire process according to its time-components. We shall see that examination of these things will suggest a new classification of sensory latencies for practical use in surface traffic, aviation and space flight. Let us now analyze the individual components as to their time consumption and put them into one frame.

In all these individual processes we must differentiate between the reaction time, comprising the latent period until action sets in, and the duration of the process as such.

The reaction time of the fixational or better interfixational movement "par saccades" (Javal, 1878) in response to a stimulus to the peripheral retina, lasts 185 milliseconds according to Diefendorf and Dodge, 1908, or 173 milliseconds according to Hackmann, 1938.

For an act of such frequent occurrence in daily life and of such importance for the protection of man, this is indeed a long time.

This process does not have, as Dodge stated, the character of a simple reaction, but rather of a determinative one, although on a lower level than the familiar determinative reactions connected with higher associations. The ocular movement must follow a definite direction and correspond to a definite extent of movement. The stimulus determines not only the beginning of the movement, but also its end. This implies that prior to its beginning the movement

must be pre-arranged in the central nervous centers as to direction and extent. But this pre-arrangement, which refers to both agonists and antagonists, requires time. The pre-arrangement is then followed by the motor latency, i.e., development of the motor impulses in the fixation centers, plus efferent conduction time, plus latency of the ocular muscles. Thus, it becomes comprehensible that the authors previously mentioned have found values of about 175 milliseconds for the reaction time of the saccadic ocular movement. Only then does movement of the eyes commence in the direction and extent determined by the stimulus.

The duration of the saccadic eye movements depends on its extent. Dodge and Cline, 1901, obtained a duration of 60 milliseconds for an extent of 20 degrees, and for 40 degrees about 100 milliseconds. (Figures 2 and 3.)

The frequent measurements of the duration of the ocular movements while reading are well in keeping with these values (Erdman and Dodge, 1898). Horizontal movement consumes a little less time than does the vertical one (Lamanski, 1869).

All in all, the whole act, ranging from stimulation of the peripheral retina to foveal distinct vision, takes one-quarter of a second. In it are contained the reaction time of interfixational movement, consuming about 180 milliseconds, plus the interfixational movement itself, lasting 30 to 100 milliseconds; and finally the latency of foveal perception, less than 50 milliseconds.

Though the conjugated, saccadic interfixational movement for obtaining an object picture on the fovea is a relatively simple one, the change from far vision to near vision and vice versa is of a complex character. There must be convergence, accommodation and pupillary reaction. However, when looking from far to a distance of six meters, only convergence comes into play, thereby preventing double vision. When looking from far to a distance of less than six meters, accommodation occurs to prevent blurring of the image. Furthermore, at near distances of less than 60 centimeters a pupillary constriction occurs and improves depth of focus.

The reaction time for these processes is not yet known, but it might very probably be just as long as that of the saccadic movement of the eye, since the precision of its execution pre-supposes a precision of the pre-arrangement in the cortical centers. Some authors investigated the process as a whole, including the reaction time, which is the most important for practical purposes. The values given in the literature on the duration of these processes must be considered while keeping in mind the fact that the various authors applied various methods, chose various distances, and investigated various age groups.

The literature mentions for convergence a value ranging from 180 to 260 milliseconds (Inouye, 1910). It takes a little longer time than the saccadic movement, according to Judd, 1907. The time in which the lens changes its form during accommodation was objectively measured by Kirchhof, 1941. His method was based on a photographic registration of the change in size which Purkinje-Sanson's reflected images on the lens undergo during accommodation. He found that the time during which the lens changes its shape amounts to 0.5 second for far to near and for near to far the time is 0.43 second. The far distance was 5.5 meters and the near distance 15 centimeters. If we disregard the over 40 age group, the values given by Tefft and Stark, 1922; Banisher and Pollack, 1929; Leukert, 1933; Robertson, 1934; and Travis, 1948, with respect to latency and duration of accommodation range from 200 to 800 milliseconds. All in all,

for the complete accommodation process, we can assume a standard value of half a second.

The pupillary constriction, which occurs during convergence and accomodation when the distance of the object is less than 60 centimeters, is of minor importance and mentioned only for the sake of completeness. This process consumes maximally three seconds.

Chains of Latencies

All these statements indicate that a process, consisting of one or more components is interposed between extrafoveal and foveal vision or in other words, between two fixations. Two of these components serve to catch the object bi-foveally, and two more to insure a distinct picture on the fovea. The former two, namely, saccadic interfixational movement and convergence, may be termed as ophthalmokinetic adjustment of the eyes for distinct vision. The latter two (accommodation and the pupillary constriction) may be designated as dioptric adjustment of the eyes for distinct vision. (Figure 4) In the following we will combine them under the term "mechanical adjustment of the eyes for distinct vision." The ophthalmokinetic adjustment is short; while the dioptric one is relatively long. This can be explained by the anatomical structure of the muscles involved in these processes. The ophthalmokinetic adjustment is effected by transversely striated, fast-reacting muscles; whereas the dioptric adjustment is effected by smooth, slow-reacting muscles. The former muscles are controlled by the fast-conducting somatic nerves; the latter by the slow-conducting autonomic nerves. From the standpoint of supersonic flight, one might call the mechanism of the dioptric adjustment fossil.

Thus it is necessary to go through a more or less long chain of latencies before distinct foveal perception is attained. They consume in all a time ranging from 200 milliseconds as a minimum to over 1,000 milliseconds. For aviation and even for fast surface travel, such a delay in the distinct perception is certainly not insignificant. For this reason it seems useful to emphasize the importance of these latencies by a specific term. It seems to me appropriate to introduce the term: chains of sensory latencies of lower order.

I use the term "sensory" because the ultimate aim here is a sensory one. The motor process of the adjustment serves as a means of obtaining distinct vision. "Lower order" seems appropriate because the intermediate processes are of a reflex, and of a more or less unconscious nature, and because the terminal stage of the whole process is at first merely the simple perception, without higher associations. The ensuing latencies of these processes involving higher associations, such as recognition* of the object, comprehension of the situation, etc., may be contrasted with the other as chains of sensory latency of higher order. In accordance with this, the so-called simple reaction time would represent a chain of senso-motor latencies of lower order, whereas the reaction times of recognition and comprehension would belong to the group of chains of senso-motor latencies of higher order. Figure 5 demonstrates this concept in a simple manner.

In former times such a classification would have been unimportant; the era of modern transportation, however, now demands it. It is useful in so far

*For recognition sometimes several fixations are necessary, in other words, a series of chains of latencies of lower order.

as it evidences the process, up to distinct simple perception as a possible chain process; whereas physiological and psychological literature has been primarily interested in temporal sequence of the higher associations and the reaction times connected therewith.

There is a remarkable difference, in that the elapsed time of the latencies of higher order varies considerably. It may vary from two-tenths of a second to several seconds. The partial processes involved overlap each other to a large extent. The chains of latencies of lower order are, as far as they come into play, more or less fixed. The system--extrafoveal perception, mechanical adjustment, foveal perception--shows no overlapping but a well-defined succession of the partial processes. It does not permit acceleration, since it works at optimal speeds under normal conditions according to Tinker, 1928, and others.

This is demonstrated by a very interesting experiment, which is described by Travis, 1948. He studied the training effect on the reaction time of recognition, together with the training effect on the complex accommodation and convergence contained therein, by repeating the experiments every second day over a period of ten days. He found that training did have a remarkable effect exclusively on the reaction time of recognition, lowering it from 1050 to 650 milliseconds; but little, if any, effect on accommodation and convergence. This experiment illustrates the usefulness of distinction between chains of latencies of lower and higher order.

Even with the relatively low speeds of surface traffic (automobile), the chains of sensory latencies of lower order may play a role which to date has not been sufficiently appreciated. In aviation their importance increases steadily. A side glance (comprising reaction time of ocular movement, plus its duration, plus foveal perception) will consume at least one-quarter of a second, especially if we include recognition. A so-called "jump of attention," therefore, should a fixational movement be enacted, would hardly consume less time. A glance to the side and back might consume at least six-tenths of a second. A glance from far to the instrument panel and back again will in any case require more than twelve-tenths of a second. The unsafe distances covered in these examples at the belocities of automobile, plane and rocket can easily be calculated.

From the standpoint of safety these considerations lead to the following conclusions.

1. In critical situations the pilot in high speed craft should use the mechanical adjustment of his eyes (especially head movements) as little as possible.
2. To facilitate this, the instrument panel must be arranged as simply and legibly as possible.
3. Pilots and car drivers must be indoctrinated on the time consumption of the various processes involved in seeing. Quick vision must be trained in respective courses.
4. Only persons with fast mechanical ocular adjustment should be assigned to high speed craft. An age limit results from the lengthening of accommodation with age. In this respect the results of Robertson are of great interest. A mentally alert man of fifty years with short latencies of higher order is certain to have long latencies of lower order if accommodation is involved. The dioptric adjustment of his eyes will take twice as much time as that of a young man of 25 years.

5. All factors causing a prolongation of the mechanical adjustment of the eyes must be taken into consideration. Such factors are:

   a. Fatigue and lack of sleep (studied by Miles and Laslett, 1931; Kiechhof, 1940; Berens and Sells, 1944).
   b. Alcohol (studied by Dodge and Benedikt, 1915).
   c. Hypoxia (McFarland, Knehr and Berens, 1937).
   d. Inadequate nutrition (vitamins A and B).
   e. Vibration (very probably vibration would affect accommodation).
   f. Light (Applied in the form of flash and intermittent light, it seems to delay the process of accommodation, an effect, which in Arcata, California, was recently termed, "frozen accommodation.")

In conclusion, I would like to say that with relation to accidents in general, the classification of chains of latencies into those of lower and higher order may prove to be very useful. Because of the simplicity of this concept, the whole problem of physiological latencies will perhaps in this way be understood much more easily by all concerned. Nothing should remain untried which may be of assistance in adding to safety and prevention of accidents.

REFERENCES

Adrian, E. D. and R. Matthews, J. of Physiol. 1927, 63, 404; 64, 279; 1928, 65, 273.

Banister and Pollack, Brit. J. Psych. 1928-1929, 19, 394.

Berens, C. and Sells, Arch. of Ophthal. 1944, 31, 148.

Diefendorf, A. R. and Dodge, R., Brain, 1908, 31, 451.

Dodge R. and Cline, T. S.: Psych. Rev., 1901, 8, 145.

Dodge R. and Benedikt, F. G.: Psychological affects of alcohol, 1915.

Dodge R.: Am. J. Physiol., 1903, 8, 307.

Erdmann, B. and Dodge, R.: Psychologische Untersuchungen ueber das Las Lesen, 1898.

Exner S. Sitz. Ber. Wiener Akad. d. Wissenschaften 1868, Abs. 2, 601.

Froehlich Fr. W. Die Empfindungszeit 1929. G. Fischer, Jena.

Hackmann, R. B., Ph.D. Thesis in Psychology, Univ. of Minnesota, 1938.

Hazelhoff, F. F., De Waarnemingstijd. De Wal Groningen 1929.

Helmholtz, H., Koenigsberger Naturwiss. Abh. 1851, 2, 169.

Inouye, Arch. f. Ophth. 77, 500, 1910.

Javal, E., Annales d'oculistique 1878, 1879.

Judd, C. H., Psych. Mon. 1907, 8, 34.

Kirchhof, Z. f. Biol. 1941, 100, 408.

Lamanski, G. Pflueg, Arch. Physiol. 1869, 2, 418.

v. Kries J. und F. Auerbach, Arch. f. Physiol. 1877, 297.

Lonkert R. H., J. Exp. Psych. 1939, 25, 257.

McFarland, R. A., Knehr, C. A. and Berens, C., Amer. J. Ophthal. 1937, 20, 1904, J. Exper. Psych. 1937, 31, 1-25.

Miles, W. R. and Laslett, H. R., Psych. Rev. 1931, 38, 1.

Monje M. Abderhaldens Handb. d. biol. Arbeitsmethoden Abt. V.T. 6.

Monnier M. and Jeanneret, R. L., Ophthalmologica 1947, 113, 1.

Pieron H. L'annee' psychol. 1925, 25, 1.

Poffenberger, Arch. Psych. 1912.

Pulfrich G. Naturwissenschaften 1922, 10.

Robertson, C. J., U.S. Nav. Med. Bull. 1934 and 1935: Arch. Ophthal. 1935, 14, 82; 1936, 15, 423; 1937, 17, 859.

Tefft and Stark, Amer. J. Ophthal. 1922, 5, 539.

Tinker, Psych. Bull. 1946, 43, 93.

Travis, 1948, J. of Exper. Psych. 1948, 38, 395.

Wirth W. Handbuch d. norm. u. pathol. Physiol. 1927, 10, 525.

DISCUSSION:

Dr. Scobee asked whether the latency of .25 second, reported for the lower order reactions, represents a total of the various constituent reactions. Dr. Scobee suggested that latency time for accommodation and for convergence might be occurring simultaneously rather than in sequence.

Dr. Strughold agreed that the constituent reactions might indeed be occurring simultaneously, and stated that the total time estimated for the lower order of reactions represented a compromise between additivity and the time of longest reaction.

Dr. Strughold reported that if accommodation comes into play, the reaction takes longer than if it were excluded.

Dr. Wald asked whether or not it was possible to reduce latencies in general by training.

Dr. Strughold replied that in his opinion latencies for the higher order reactions can be generally speeded up by training.

Dr. Berens asked whether the speed of fusion from near to far accommodation could be increased by training.

Dr. Strughold suggested that this would not be possible, but that training of such responses as recognition was possible.

Dr. Fry commented that he believed there to be some indication that accommodation and convergence reactions can occur simultaneously. He suggested that what is needed is awareness of the exact position of the object in space in order that such simultaneous reactions might be made.

Dr. Fry suggested that perhaps one could train in a dark surround or with one eye occluded so that associated reactions could become well organized.

Dr. Beck commented on the role of anticipatory responses in keeping the organism "keyed up". Such responses tend to reduce the time for lower order reactions.

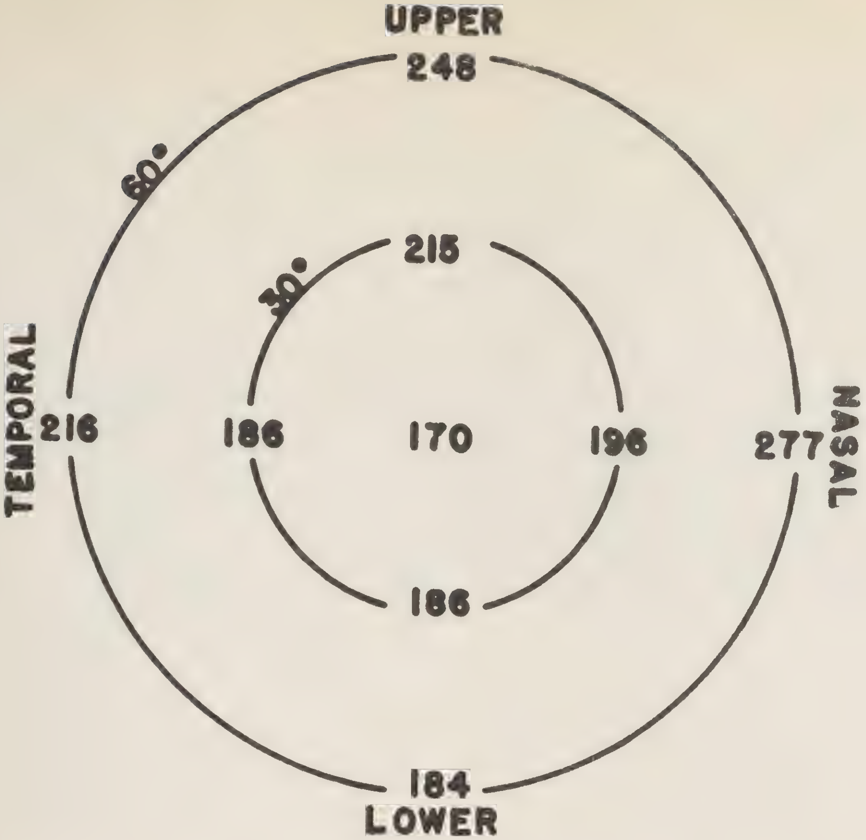


Figure 1: Reaction time to stimulation at different parts of the retina. Stimuli were applied at the fovea and at points 30° and 60° from the fovea along the horizontal and vertical meridians. The reaction time is expressed in milliseconds (after data of J. v.Kries and F.Auerbach).

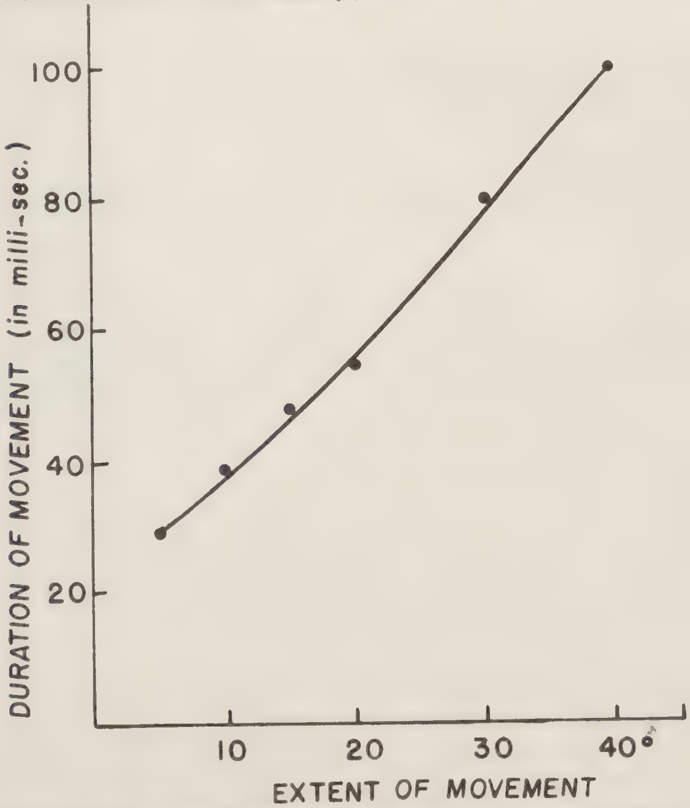


Figure 2: Duration of saccadic eye movements (after data of Dodge and Cline).

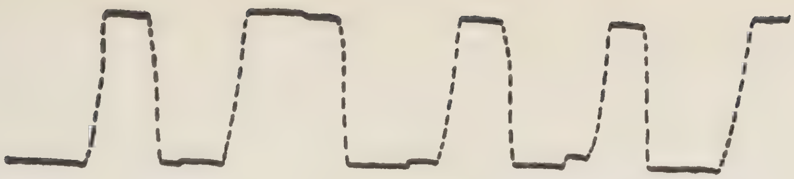


Figure 3: Long saccadic movements. The eye shifted back and forth between fixation points 40 degrees apart. The light beam was interrupted 100 times per second, and the duration of the movements can be found by counting the dashes. The heavy lines are fixations, during which the separate flashes of the light are too close together on the record to be distinguished. As the original eye movements were horizontal, the figure is best seen from the side (Dodge and Benedict).

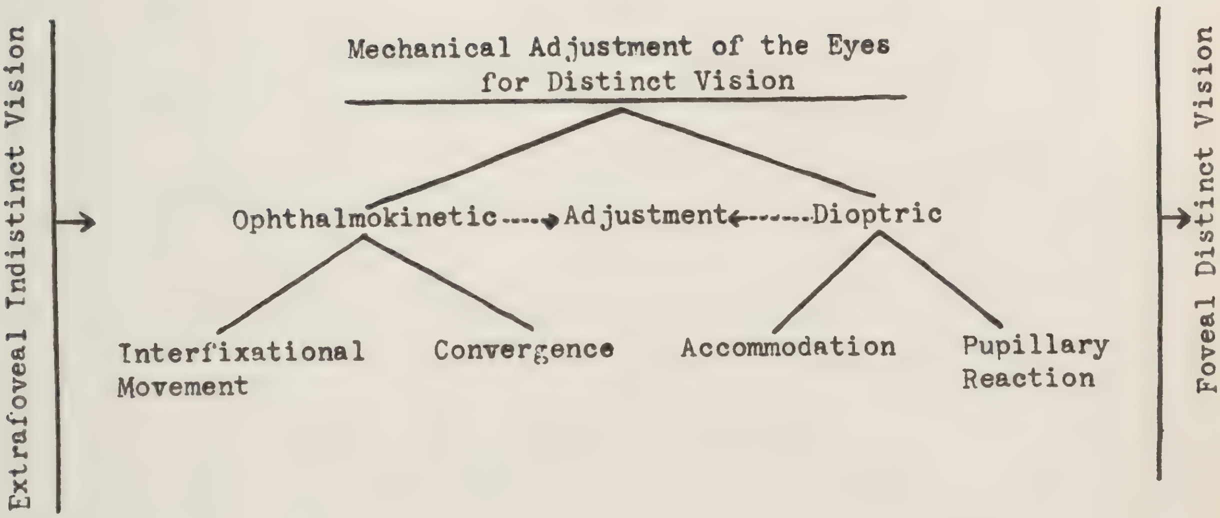


Figure 4

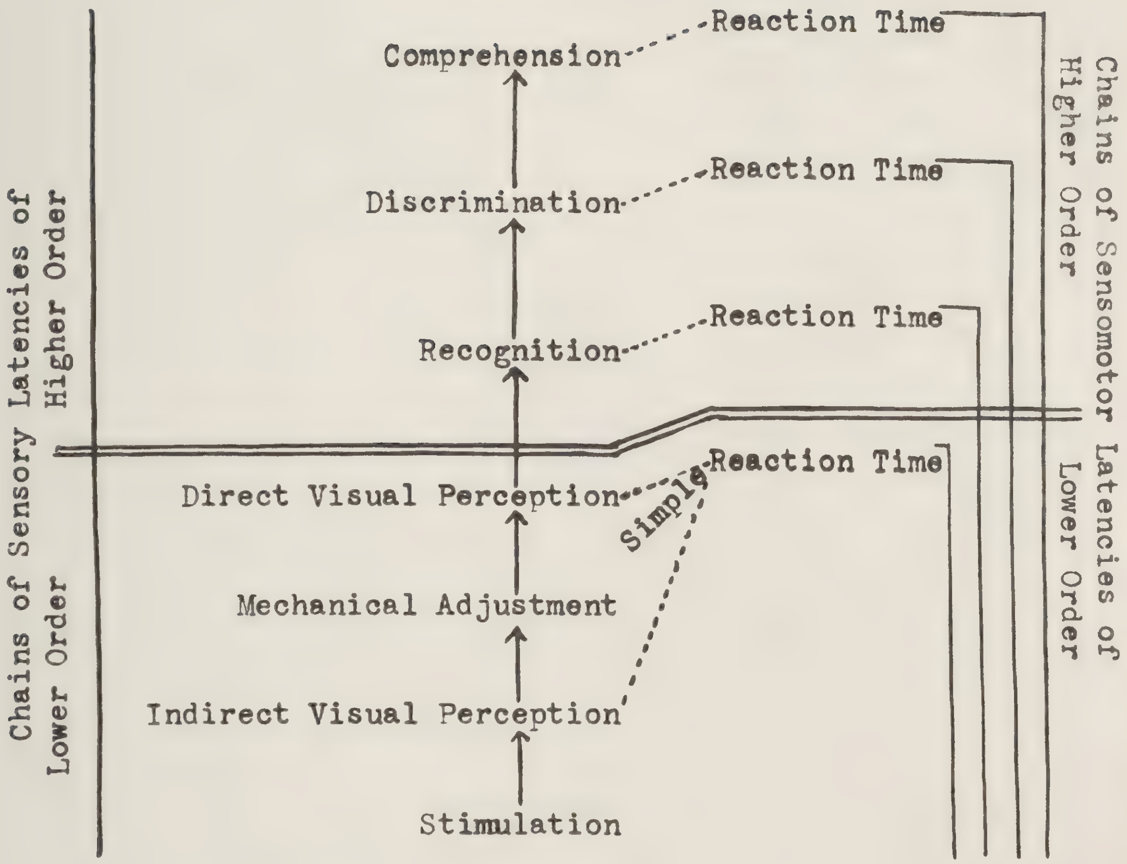

Chains of Sensory Latencies of Higher Order
Chains of Sensory Latencies of Lower Order
Reaction Time
Comprehension
Reaction Time
Discrimination
Reaction Time
Recognition
Reaction Time
Simple
Direct Visual Perception
Mechanical Adjustment
Indirect Visual Perception
Stimulation
Chains of Sensomotor Latencies of Higher Order
Chains of Sensomotor Latencies of Lower Order

Figure 5

VISUAL ACUITY AT LOW LEVELS OF ILLUMINATION
(Preliminary Report to Vision Committee)

Forrest L. Dimmick
Medical Research Department, New London Submarine Base

The essential aim of our project is to measure visual acuity through a wide gamut of target brightnesses in terms of visual angle with a single type target, the checkerboard, as modified from the Bausch & Lomb Orthorater slides and evaluated in the A.G.O. study which is familiar to all of you. In addition, we are raising the question whether the relation of acuity to brightness is further modified by the type and degree of ametropia of the observer.

This project has a long past history, and it is not my intention at the moment to review the factors in the literature that have determined our mode of attack. However, I would like to call attention to some of the advantages in the use of the type target which we have chosen. The A.G.O. study has found that the checkerboard at moderate intensity levels, measures 90% in terms of one factor which they call "resolution." If the checkerboard may be taken as essentially a form of grid, then according to other investigations, we may take it as a measure of retinal resolution at high intensities. In like manner, we may assume that at very low levels of illumination, lenticular factors are at a minimum, so that once again the visibility of the target will depend upon retinal factors. To the extent that these assumptions are valid, we may determine the effect of lenticular distortions at brightness levels lying between the extremes. The checkerboard target, therefore, becomes particularly applicable to the second part of the problem as stated above, namely, the affect of ametropia on acuity at various brightness levels, especially those at which the photopic and the scotopic mechanisms cooperate.

It is convenient and logical to divide the brightness range into four steps which we have labeled and roughly defined as (1) Scotopic, 4 log μμL to 6.5 log μμL; (2) Mesopic, 5.5 log μμL to 8 log μμL; (3) Photopic, 7 log μμL to 10 log μμL; and (4) High brightness 10 log μμL to 14 log μμL. The present study is devoted to the first of these levels, the Scotopic.

<u>Apparatus</u> - <u>Target</u> See Figure 1

The variable grid form of checkerboard target was chosen to provide a constant size factor for peripheral vision. The size of the checkerboard area and of the three gray squares is 47 cm. The checkers range in size from 7 mm to 155 mm by a factor of 1.09 which gives units of 1/8 $\log_2$. Viewed from a distance of 10 feet the range of visual angles is 8 min. to 175 min. (2° 55') by the same factor. The individual checkerboard in use is carried in a clip-mounting on the rotating target.

The three gray squares are carefully equated in brightness to the checkerboards by calculation and by empirical comparison with the checkerboards at fusion distance and at fusion brightness. They are permanently mounted on three corners of the target. The distance between adjacent edges of any two squares is 26.7 cm.

The shaft carrying the target is hollow and carries a red light which provides a fixation point 1 cm. in diameter.

The distance of 10 ft. from the observer's eye to the target has been established in order to obtain the largest practicable visual angle with the equipment available. The angles provided are as follows:

center of fixation to inside corner of checkerboard	3.6°
diagonal of checkerboard	12.6°
diagonal of target	32.0°

Photometry

The effective field of view is painted white and illuminated by means of an elipsoidal projector. Brightnesses within the area of the target vary by less than 2%. Some diminution in brightness occurs toward the extreme periphery but is not noticeable over a field of some 90 degrees.

Brightness of the target area is controlled by setting the projector to give 1 millilambert from the white surfaces of the target. This measurement is checked weekly.

For observations at a particular brightness level, Wratten neutral filters are inserted in the beam from the projector. Filter combinations of densities from 5. to 2.5 by .5 density steps give a range of brightnesses of the target and field of log 4 $\mu\mu$L to log 6.5 $\mu\mu$L.

Adaptation level

Observers wear red adaptation goggles for 5 minutes when they first enter the observation room. During this time they read the instructions and adjust the chair and head rest. Then the lights are turned off and the observer sits in complete darkness for 7 min. to 15 min. according to the brightness level at which testing is to be done. Finally the projector is turned on at the light level of the experiment and after another 5 minutes observations begin.

Procedure

A standard method of constant stimuli is followed. In preliminary series the approximate range of target sizes is determined, within which the transition from complete resolution to no resolution occurs. Five targets are chosen so that the per cent resolution of the easiest target will be just less than 100% and of the most difficult just greater than 0%.

The observers are instructed as follows:

"You are going to be shown a series of targets, similar to the one above. There are three gray squares and one checkerboard on the white target field. After each trial you will respond whether or not you see the checkerboard and if so, in what position you see it--up, down, right, or left.

1. You will be given red goggles to wear for approximately five minutes while preparations are being made.
2. Seat yourself in observer's chair and arrange chin rest in position comfortably. You should be able to see red fixation light through the opening in the shutter.

3. When the lights go out there will be a period of adaptation in total darkness, then a period at the working light level.
4. When the projector is plugged in, put occluder on left eye. Take position and get ready to observe.
5. When A gives "Ready?" signal, fixate red light and when it is clearly seen respond "Ready."
6. At your signal, the A will open the shutter for 3 seconds.
7. During the 3-second period, maintain constant fixation upon red light while examining the whole target to determine whether you can perceive the checkerboard.
8. As soon as the shutter is closed, respond "Yes" if checkerboard is seen, "No" if not seen. If response is "Yes" also give position as "Up," "Down," "Right," or "Left."
9. Make use of all possible cues but do not guess at any time.
10. The microphone button should be depressed only when your responses are given.
11. Between exposures you should attemp to relax your eyes by "gazing off into space." Avoid looking at the fixation point or shutter.
12. If at any time the field becomes obscured, report the fact immediately to E over the microphone."

Normally an observation period at a given light level yields 24 judgments with each of 5 targets displayed at random in the 4 positions. The target sizes are presented in a chosen random order.

The data in this report are from five observers with two observation periods or more, at each light level. Thus every liminal curve is based upon at least 240 judgments.

Results

Figure 2 shows the cumulative distribution curves obtained from two observers at 5 light levels. The curves plotted on linear paper are the actual data and are not smoothed. The same data are plotted on probability paper and the theoretical probability lines drawn.

These two observers were chosen for presentation because one appeared slightly hyperopic and the other slightly myopic on the Orthorater, and neither wore ophthalmic corrections. It is interesting to note--though it may be only coincidence--that the hyperope's curves show less deterioration of acuity with decrease of brightness than do the myope's and the normal's.

Figure 3 shows the change of acuity with brightness in this range. Our five observers cover a fair range of individual differences in acuities. The difference in rate of change, as indicated by the slopes of the lines, may have some significance. We are not prepared to go far with interpretation of the data until we have completed the full quota of 10 or more observers, and reduced our photometric measurements to more nearly absolute terms.

DISCUSSION:

Dr. Scobee asked Dr. Dimmick what he meant by "slightly myopic" and "slightly hyperopic", and how these ratings were assigned on the basis of Orthorater scores.

Dr. Dimmick replied that these descriptive terms were based on relative acuity scores at near and far. If a subject exhibited slightly better acuity at near than at far, he was designated "slightly myopic", and vice versa.

Dr. Wald commented upon the considerable evidence for the existence of "night myopia". He described briefly the experimental findings concerning the relative fixity of focus of the eye under scotopic conditions. He asked whether Dr. Dimmick was on the lookout for this condition in his studies.

Dr. Dimmick replied that he was aware of the phenomenon, and that in fact Dr. Burger, who began the study, started out to investigate just this problem.

Dr. Miles reported that when the checkerboard targets are used for central vision and when no fixation provision is made, the line character of the checkerboard is seen in only part of the pattern. He asked whether Dr. Dimmick had received any reports from his observers as to the qualitative appearance of the various parts of the checkerboard targets under the conditions of parafoveal vision.

Dr. Dimmick said that he had not received any such reports from his observers.

Dr. Blackwell suggested that the fixed focus reported by Dr. Wald exists only when there is no adequate stimulus for fixation presented in the fovea. Dr. Blackwell reported experiments recently conducted in which the eye was shown to accommodate perfectly in dim light for distances between 1.5 and 30 feet. These experiments were conducted under adequate foveal fixation. He suggested that so long as Dr. Dimmick maintained adequate foveal fixation, the fixity of focus reported by Wald could not be expected to occur.

Dr. Wald agreed that this interpretation of his results was correct.

Dr. Blackwell asked whether Dr. Dimmick had determined the goodness of fit of the psychophysical data to the cumulative normal function.

Dr. Dimmick reported that he did not have evidence of the goodness of fit.

Dr. Dimmick expressed his belief that any kind of lens effect, even inadequate accommodation, would have very little influence on visual functions at these levels.

Dr. Hulburt asked Dr. Dimmick for clarification of his remark that there were always differences in average reflectance of the squares in the checkerboard patterns. He suggested the possibility that if such brightness differences were not eliminated, discrimination of the correct square would be based upon a brightness discrimination rather than upon resolution.

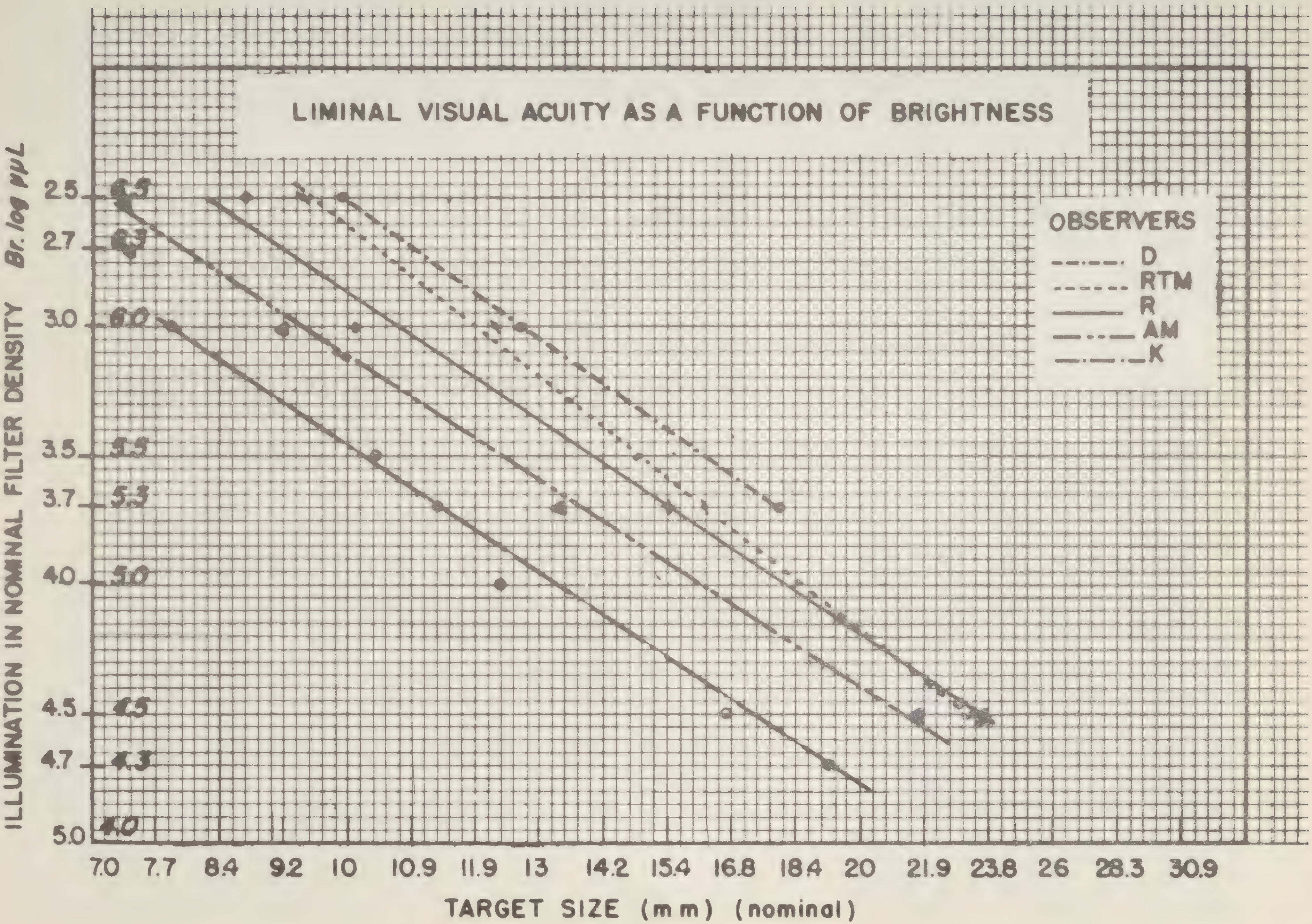
Dr. Dimmick reported that attempts were made to photometer the brightness of the squares so as to select targets with equivalent brightness in the four quandrants of the checkerboard patterns. One method for doing the photometry involved placing the checkerboard targets in a long tunnel and observing them from the rear of the tunnel. The second technique involved direct low-level photometry of the average brightness, utilizing the approximate viewing distances at which the subject was placed.

Dr. Dimmick stated also that the observers were being required to give qualitative impressions about the targets rather than making forced discriminations such as Blackwell has recommended. He stated that this method would eliminate the importance of brightness differences in the targets since the observers would be alerted for brightness differences and would not report answers based upon them.

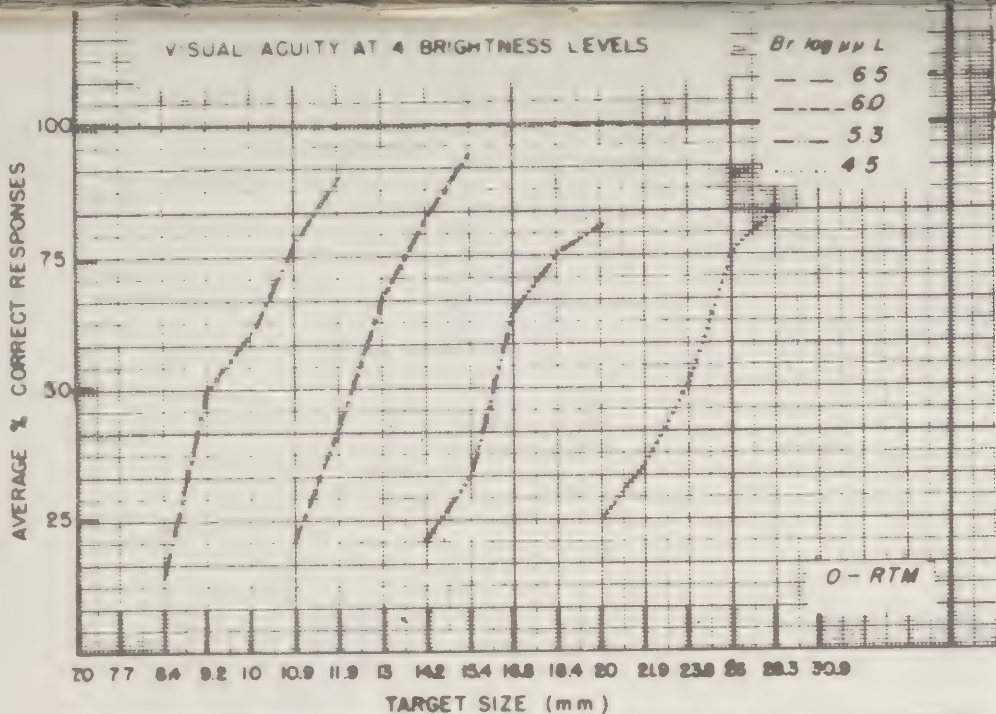
Dr. Blackwell questioned the conclusion Dr. Dimmick had reached, and expressed his doubt as to what the subjects would do in the case that both brightness differences and qualitative differences based on resolution were present.

Dr. Hardy expressed his concern with the statement of photometric procedures utilized. He expressed his belief that the equivalence of brightness of the checkerboard targets was of extreme importance in the discriminations measured by Dr. Dimmick. He expressed his belief that the direct low-level photometry could not be considered satisfactory because of the poor precision. He questioned the use of the long tunnel method with high-level photometry because of the possibility of differences due to the gloss characteristics of the materials utilized.

Dr. Dimmick expressed his belief that the photometric measurements made were not dependent upon the gloss characteristics of the charts.



LIMINAL VISUAL ACUITY AS A FUNCTION OF BRIGHTNESS
OBSERVERS
D
RTM
R
AM
K
ILLUMINATION IN NOMINAL FILTER DENSITY
Br. log μμL
2.5
2.7
3.0
3.5
3.7
4.0
4.5
4.7
5.0
6.5
6.3
6.0
5.5
5.3
5.0
4.5
4.3
4.0
7.0
7.7
8.4
9.2
10
10.9
11.9
13
14.2
15.4
16.8
18.4
20
21.9
23.8
26
28.3
30.9
TARGET SIZE (mm) (nominal)


VISUAL ACUITY AT 4 BRIGHTNESS LEVELS
Br log μμL
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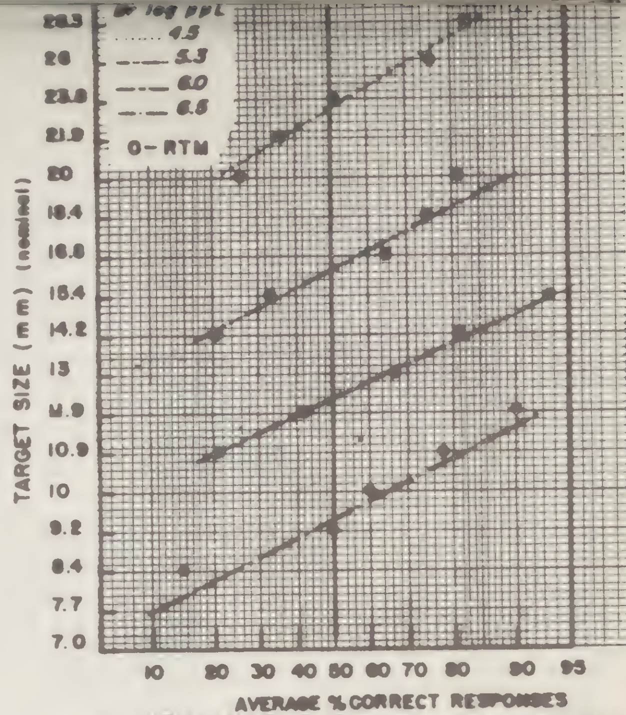
6.0
5.3
4.5
O - RTM
AVERAGE % CORRECT RESPONSES
TARGET SIZE (mm)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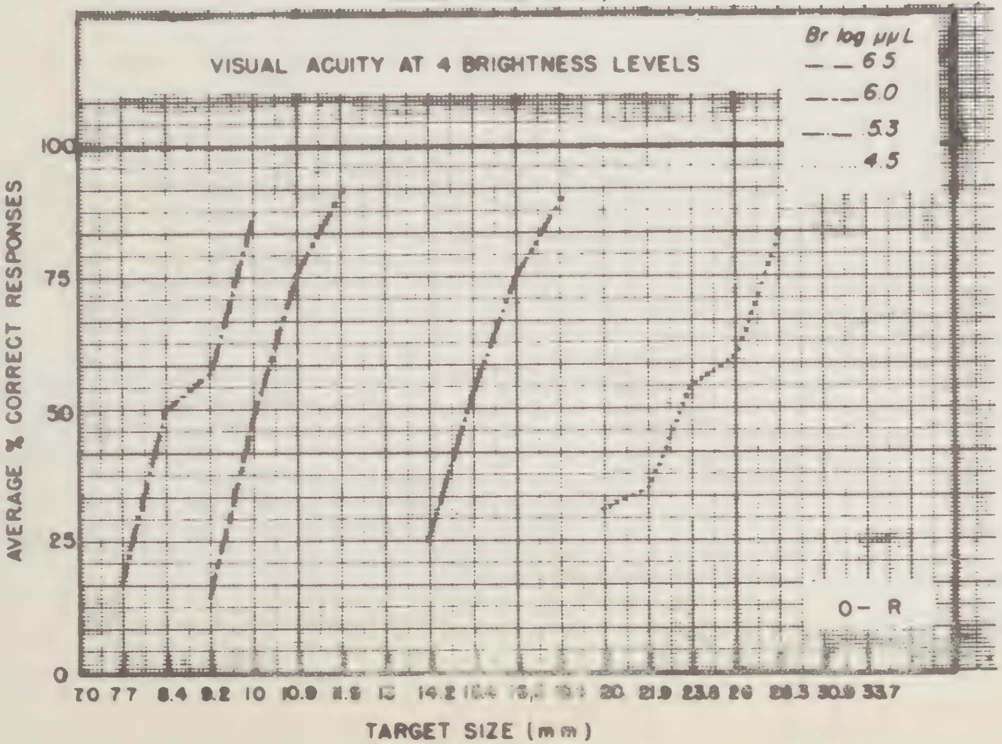
O - RTM
TARGET SIZE (mm) (nominal)
AVERAGE % CORRECT RESPONSES


VISUAL ACUITY AT 4 BRIGHTNESS LEVELS
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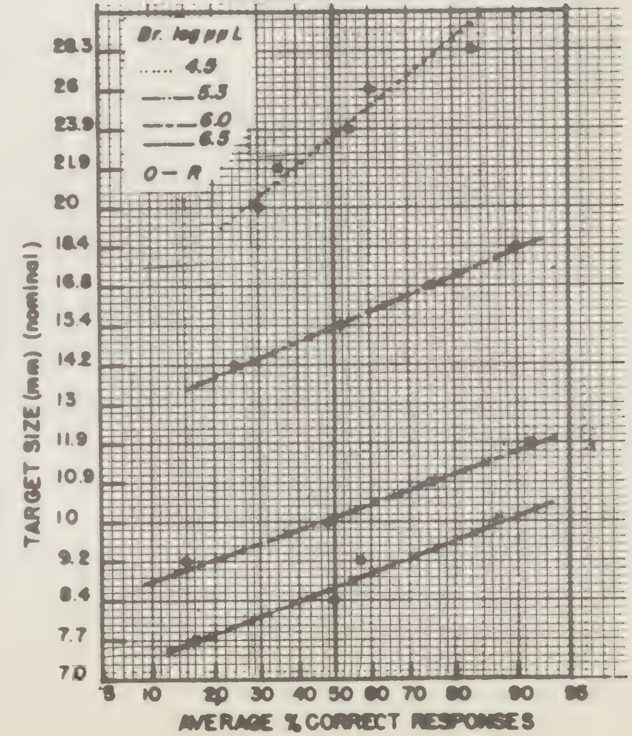
TARGET SIZE (mm)


Br. log μμL
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AVERAGE % CORRECT RESPONSES

ABSTRACT
THE DISCRIMINATION OF VISUAL NUMBER*

John Volkmann
Mount Holyoke College (Navy)

<u>How many</u>? This is one of the first questions asked in operational situations. How many planes are there? or ships? or men? The answer to this question often decides what must be done next. Consequently we need to know how people discriminate the number of things that they see.

One of the oldest psychophysical experiments, conducted by Jevons (1), suggest that small numbers of objects are not discriminated in the same way as large numbers. There grew up gradually in the history of psychology the notion of a "span of apprehension": a certain number of objects, and no more, can be "immediately" and accurately perceived. This notion persisted even after the span of apprehension became statistically (and arbitrarily) defined as the number of objects that could be perceived correctly 50% of the time. Saltzman and Garner (2) have recently shown, however, that the entire idea of a span of apprehension is inappropriate in the first place. They measured the time between the presentation of the stimulus-objects and the subject's spoken report, and showed that this time increases with the number of objects presented. In the extreme case, it takes longer to report 2 objects than 1. There is no such thing as the "immediate" apprehension of number.

But even if we do not think of a fixed span of apprehension, it is still possible that small numbers of objects are not discriminated in the same way as large numbers. This view has been advanced and supported by Taves (4). In particular, Taves found that most of his functional relations exhibited a discontinuity between 6 and 8 stimulus-dots.

The experiments to be summarized here all involved the simultaneous presentation of randomly arranged, circular white dots in a dark field. The subjects were instructed to report the number of dots in the field. The exposure of the dots was sometimes brief (0.2 sec.), and sometimes lasted until the subject made his report. The time between the presentation of the stimulus and the subject's report was always measured. The measuring system consisted of a microphone, an amplifier, a holding relay, and a chronoscope. After making the report, the subject indicated the degree of his confidence in that report. The indication of confidence is a crude measure, but one that yields interesting results. The number of stimulus-dots presented varied from one experiment to another.

In the first experiment, two groups of subjects were shown numbers of dots varying from 1 to 210. One group was instructed primarily for <u>speed</u> of report; the other primarily for <u>accuracy</u> of report. If we examine the <u>median</u> reported number as a function of the stimulus number presented, a characteristic result appears. Under both conditions of instruction, most subjects show high accuracy of report up to 5 or 6 dots. Seven and 8 dots tend to be reported slightly too high. At about 10 dots the median report is nearly accurate. Dot numbers

*These experiments were carried out under subcontract with Systems Research, The Johns Hopkins University, operating under Contract N5-ori-166, Task Order I, with Special Devices Center, Office of Naval Research.

larger than 10 are usually underestimated, and the error at large dot-numbers is considerable. The same picure emerges even more clearly when the percent-error of report is plotted against the presented number of dots(Fig.1). There are large individual differences in estimating the larger dot-numbers, and some subjects will even overestimate them by absurd amounts.

The measurements of report-time confirm completely the findings of Saltzman and Garner. (See Fig. 2). The report-time increases continuously from 1 dot to 5 or 6 dots. In order to analyze the data in the region just above 6 dots, the branch of the curve below 6 dots was rectified. That is, instead of plotting the median report-time against stimulus-number, a convenient empirical function of report-time was plotted instead. The result of this transformation was to make the points from 1 to 5 or 6 dots fall in an approximate straight line on the plot; and to show that at about 5 or 6 dots there appears a discontinuity in slope (Fig. 3). Taves, too, was right; even though there is no "span of apprehension", small numbers of dots (1 to 5 or 6) are still not discriminated in the same way as larger numbers. The confidence data, when similarly rectified, also show a discontinuity in slope at 5 or 6 dots. The discontinuity appears in both the group data and the individual data. The instruction for speed produces considerably more speed. The instruction for accuracy probably produces slightly more accuracy.

So there is a separate process for discriminating stimulus-numbers of 6 or less. We now propose a new term for this process: subitizing. The term suggested for the second discriminatory process, concerned with 7 or more dots is the familiar one of estimating. The term counting might be reserved for the obvious process of pairing off each successive response in a series of numeral-responses with a separate stimulus-dot. It is now possible to summarize some of the more important findings as follows: subitizing is on the average more accurate and more rapid than estimating, and it is attended with more confidence.

Prolonged exposures probably occur more often at sea or in the field than the brief or flash-exposure. In the second experiment, the exposure of the dot-field was prolonged until the subject had made his report. The instructions called for accuracy, but they did not require explicit counting of the dots. The measurements of report-time were rectified in the same way as the measurements in the first experiment. (See Fig. 4). A similar inference can be drawn: even with prolonged exposure, dot-numbers from 1 to 5 or 6 are discriminated in one way (subitized) and larger dot-numbers in another way (estimated). The discontinuity in slope appears even more clearly when the second branch of the function (for 7 dots and more) is rectified, instead of the first branch.

In the next experiment, the subjects were explicitly instructed to count out loud. In most parts of the experiment, they were also told in what groups to count, i.e., by 1's, 2's, 3's, 4's, or 5's. Even when the subjects had to count by 1's, their median report-times (as rectified) show evidence of the process of subitizing. Because subitizing has made the counting superfluous, the words one, two, three, four, five are spoken at a high rate, and slurred over. The graphical indication of a discontinuous slope is small, but it is still there.

The results were also analyzed for a quite different purpose: to find the most efficient way of counting a random field. There are at least two sets of measurements to be considered: accuracy and speed. Fortunately, the results seem to be perfectly plain. Up to some reasonably large number like 200 dots,

it is more accurate to count by 2's than by any other size of group (Fig. 5). What is just as important, it is considerably faster to count by 2's than by 1's, and it is almost as fast to count by 2's as by 3's, or 4's or 5's. It occurred to us that our subjects might have arrived at this conclusion anyway on the basis of ordinary experience, so that the next step was to instruct a new group of subjects to count out loud by any grouping or combination of groups that they might wish to select. They did not uniformly count by 2's, and most of them used a combination of groupings rather than just one. The experiment showed that it is more accurate to count by 2's than to count at random, and it is almost as fast. Perhaps some use can be made of these results in naval or military practice.

The next experiments were concerned with the effect of supplying an accessory field of dots, exposed before the principal field. The purpose of this accessory field was to aid the subjects in making their estimates. It is called an anchoring stimulus, and the effects are called anchoring effects. The subjects were told beforehand (and told correctly) how many dots there would be in the anchoring field. As we expected, supplying an anchoring field of 6 dots had very little effect. One may suppose that there is no need for an anchoring field when subitizing can take its place, and under many circumstances, 6 dots are subitized. Supplying an anchoring stimulus at 49 dots, however, exerts pronounced effects upon accuracy, variability, and confidence. The percent error at 49 dots is reduced virtually to zero, and percent error above 49 dots is decreased. Percent error considerably below 49 dots is, however, somewhat increased; an anchoring stimulus can injure as well as aid the accuracy of report. An anchoring field of 49 dots decreases the variability of estimation, especially in a broad region above 49 dots.

Questions have been raised about the effect of practice on subitizing and estimating. We were interested principally in subitizing, so that the stimulus-series ran from 1 to only 10 dots. There was no differential reinforcement; i.e., the subjects were never told whether their reports were correct, or what the stimulus-number had been. Naturally enough, the accuracy of report did not increase appreciably, although the median number reported underwent some change. It should be noted that the accuracy of report was relatively high in the first place. Two other changes were quite pronounced, however. At the end of 60 practice trials, both the speed of reporting and the confidence in the report have definitely increased. Fig. 6 shows the effect of practice on the speed of reporting.

A theory of the process of estimating has already been outlined by Taves. It accounts for estimating in terms of scales of absolute judgment anchored at one end and extended according to a modulus which is itself a varying quantity. In developing a theory of subitizing, one might refer to two basic sets of data: 1) the variation of median report-time with dot-number, already referred to; 2) the frequency-distributions of report-times, which vary in shape as the number of stimulus-dots increases. It is tempting to think of some kind of central discriminating mechanism that has 6 channels. The channels could all be used simultaneously, but what goes on in one channel is not completely independent of what has been happening in some of the other channels. Whether one follows this line of thinking or a different one, it would be desirable to know how the process of subitizing works when the dots are not given simultaneously, but in rapid succession (in different places). An apparatus for producing these stimulus-conditions is nearly done.

The theory of counting ought to receive an impetus from the work of Taubman (3) who varied both the number of dots and the rate of stimulation, and obtained reports of numerousness. The visual stimuli were flashes of light that appeared in one place. The largest number of flashes presented was 10. As the time-interval between successive flashes increased, the maximum number of flashes correctly reported increased at first slowly, then abruptly to 10. This result suggests that the human counting mechanism (like most counters) has a latent period of definite length. After registering one item, it takes some time for the counter to return to its original state so that the next item can be registered. When the counting mechanism is driven at slightly too high a rate, it very soon becomes jammed, and only the first few items can be counted. We are planning to check the shape of this curve by presenting a larger number of intermediate stimulus-rates. An apparatus has now been prepared for this purpose. It consists of an impulse-generator whose rate is continuously variable, and a pre-determined counter. The counter shuts off automatically at any given predetermined number of impulses between 1 and 999.

REFERENCES

1. Jevons, W. S. Nature. 1871, 3, 281-282. Found in Woodworth, R. S., Experimental Psychology. New York, Henry Holt and Company, 1946, pp. 685-687.

2. Saltzman, I. J. and Garner, W. R. Reaction time as a measure of span of attention. Jour. Psychol., 1948, 25, 227-241.

3. Taubman, R. E. Studies in Judged Number. Doctoral dissertation, Columbia University. (To be published)

4. Taves, E. H. Two mechanisms for the perception of visual numerousness. Arch. Psychol., N. Y., 1941, No. 265, p. 47.

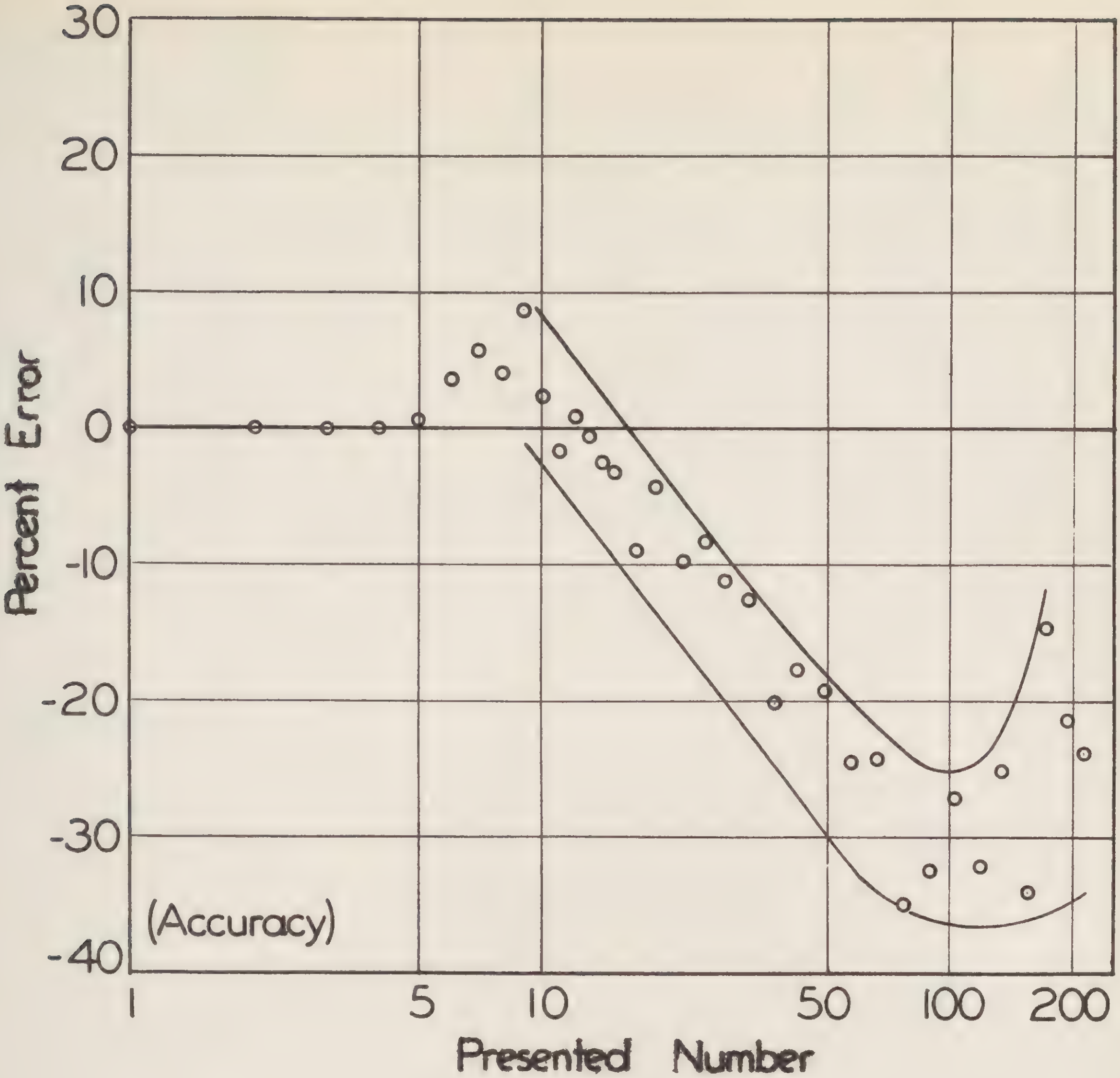


Figure 1

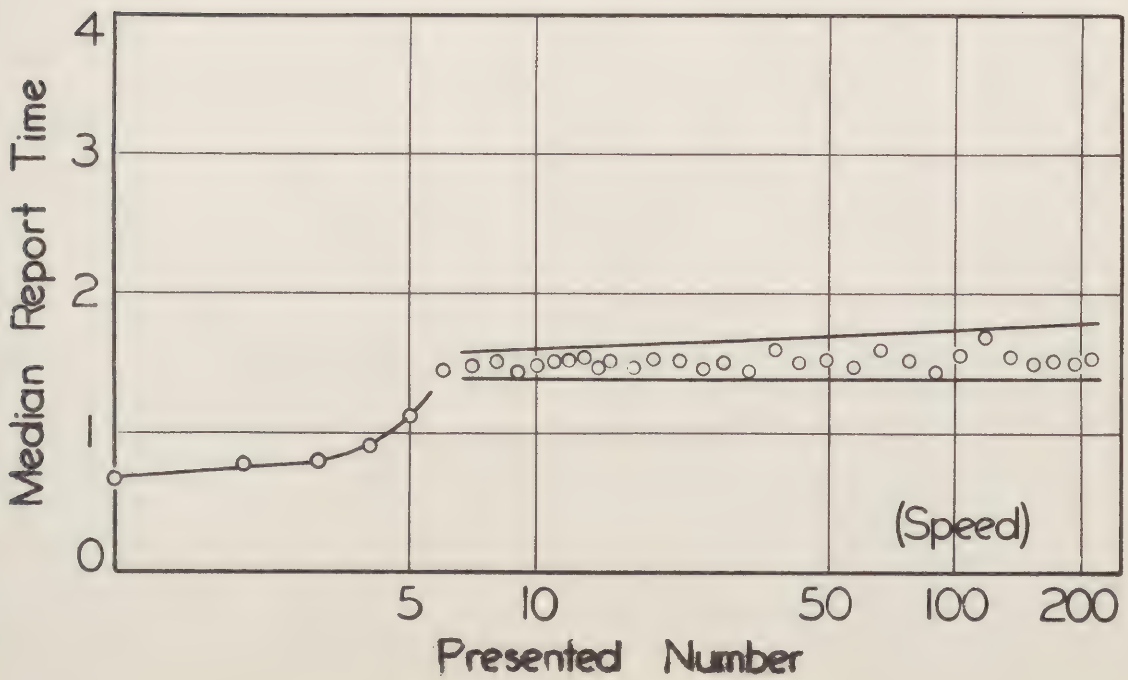


Figure 2

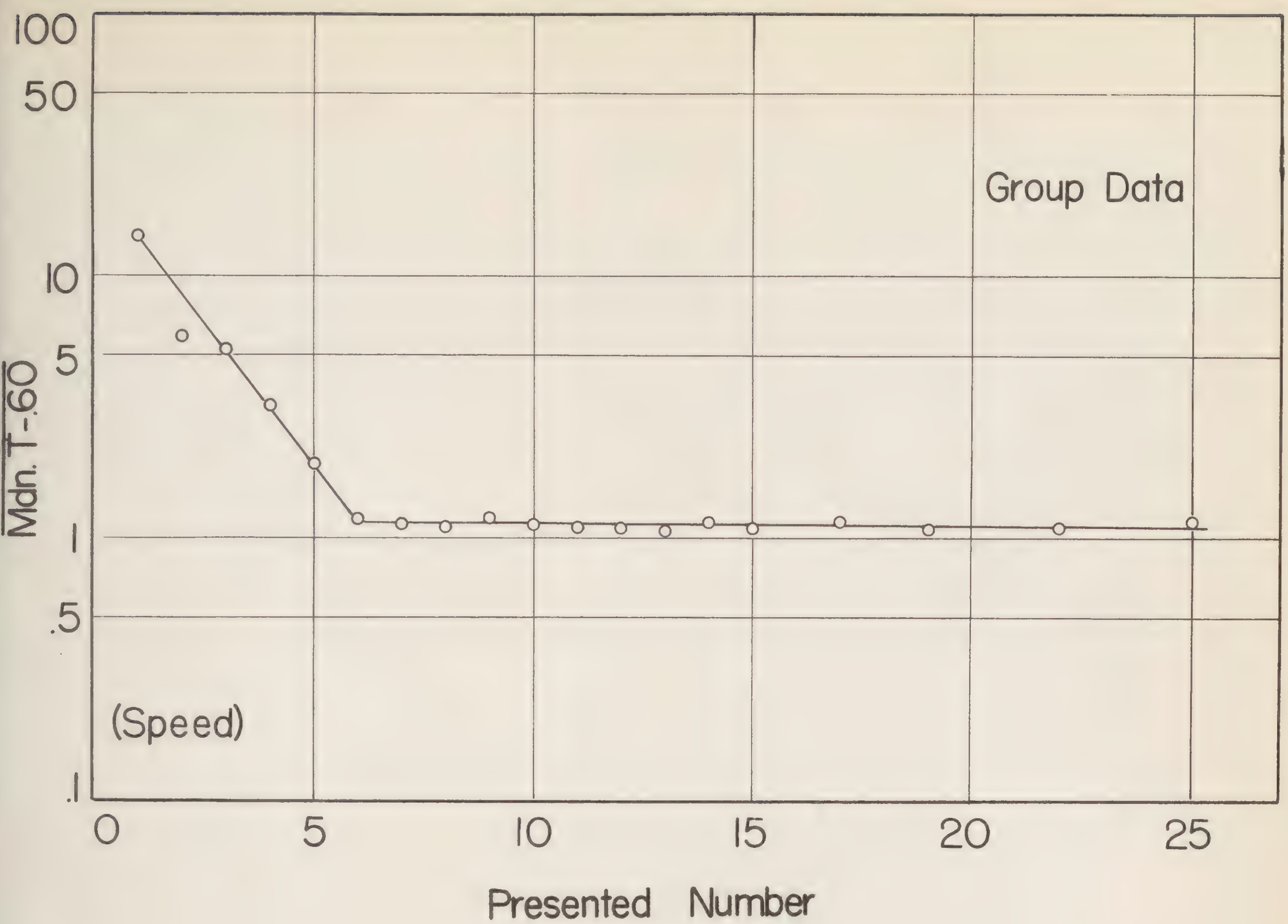


Figure 3

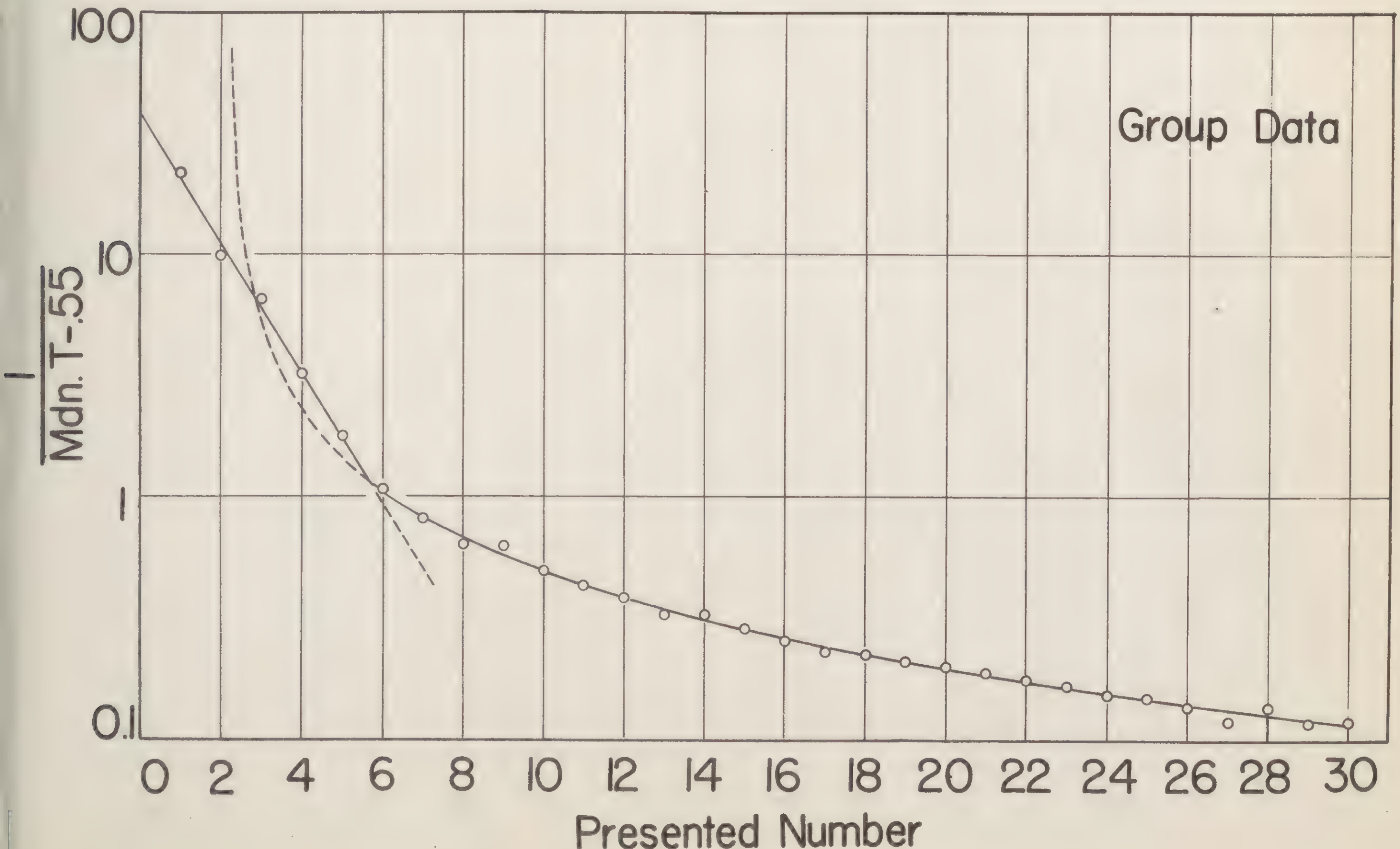


Figure 4

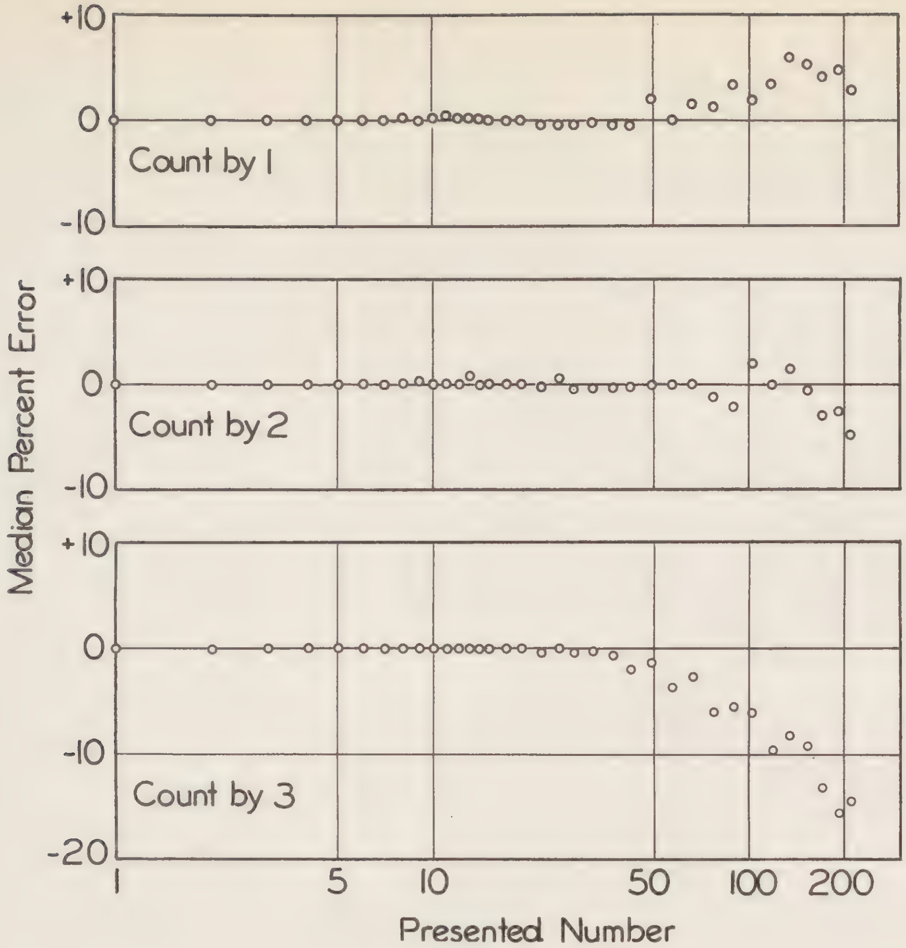


Figure 5

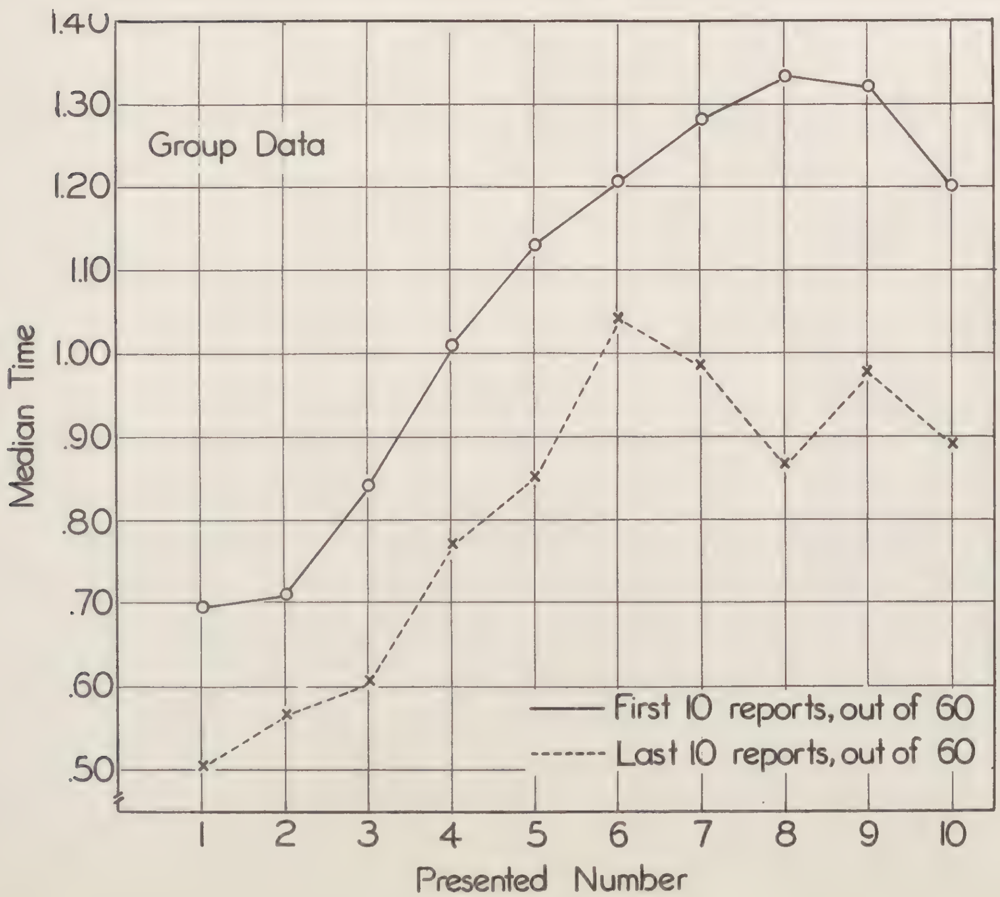


Figure 6

ON THE SEEING-FREQUENCY FUNCTION.

W. J. Crozier

Biological Laboratories,
Harvard University.

I.

Better knowledge of near-threshold seeing-frequencies, as dependent on stepped magnitudes of stimulating energies, is required for purposes of general theory. It is also significant for a variety of practical problems. Care must be exercised when attempting to transfer the essence of the most carefully determined measurements to the complex realities of "free seeing"; yet even here it is of assistance if the theoretical situation for approximately ideal cases can be clarified.

I came in a somewhat indirect way to the examination of this matter. The route should be sketched, because in following it there evolved a not uninteresting set of independent internal checks upon certain conclusions respecting the nature of the seeing-frequency function as thus far established.

During 1940-41, as natural part of an investigation of the flicker-recognition contour with small light-time fractions, it seemed necessary to establish for our observers the curves relating threshold-intensity to exposure-time, for isolated flashes, employing target images relevant to the flicker measurements. What had been conceived as a simple enough task, in view of the treatments of this question in the existing literature, turned out to be something of a challenge. The usual presentation commonly assumed the constancy of the $I \times t$ product over a considerable range of t below about 0.1 sec. We could not find this. It was clear that the story struggling to be told by data from a variety of sources, already recorded by others, was of the same kind. The plot of $\log \Delta I_0$ vs. $\log t$ does not exhibit a limiting slope of -1, in general; nor is the limiting plot rectilinear; and it is not a continuous function - it has 'cusps' on it, occurring at very definite places on the time-scale. The lumping of heterogeneous data can obscure these cusps, but decently homogeneous data with a reasonably close array of points always brings them out.

A great deal of effort was expended by Dr. E. Wolf and myself in the testing of this unexpected situation. Shutters and their calibration were investigated. Wavelength composition of light, image area, retinal location, level of light adaptation, visual pattern endpoints, partial pressure of O_2 respired, and certain other variables (including those in the uniocular-binocular comparison) were tested in the effort to shift or modify the expression of the 'kinks' or 'cusps' in the $I - t$ curves. The outcome of upwards of 24,000 measurements in this group of experiments left us with a solid conviction of the reality of these 'cusps', of the stability of their positions on the time scale, and of their independence of specific visual conditions. These experiments, subsequently amplified in several directions, have given a considerable body of data for the discussion of a variety of questions in visual theory; but they gave no clue to the intimate nature of the causation of the 'kinks' in the $I - t$ contours.

II

The investigation was interrupted by a war-time assignment which took me into a quite different kind of activity. In sundry strange places I did however occasionally speculate on the problem. It seemed clear that the 'cusps' must be regarded, at a first guess, as being located at exposure-times where, for reasons unknown, the mean threshold intensity is higher than it "ought" to be; at such points it could be thought that the total population of available 'effect elements' is somehow made to be smaller than at neighboring exposure-times.

It appeared that two ways of testing this should be especially productive. Certain others have been partially looked into. Of the two chief kinds of test I shall mention the first only very briefly. It could be predicted that the form of the dark-adaptation contour, determined after a fixed light-adaptation, should be a function of the exposure-time used for the test-light, and - at the fovea, and for both branches of the usual peripheral curve, - so dependent on the exposure-time that the S. D. of the probability integral connecting $1/\Delta I_{\theta}$ with log dark-time should be relatively smaller, and the abscissa of inflection ($\log t_{\theta}$) of this curve should be relatively higher, at those test exposure-times associated with kinks in the I, t contour. Rather elaborate confirmation of this has been obtained. The form of the dark-adaptation curve is definitely not invariant with respect to the exposure-time of the test-light. Interesting consequences flow from this fact, quite apart from the confirmation of the existence of 'critical' exposure-times.

III.

The second method of checking involved determination of seeing-frequency curves as a function of intensity, and of exposure-time. It also involved certain obviously necessary elaborations of what I take to be a procedure common in some recent experiments of this type.

All of the experiments concerned in this summary - those already mentioned as well as those to follow - were carried out with a single piece of quite flexible and precise apparatus ("Discriminometer"), and with a small number of observers. In fact the data about to be discussed were provided by a single (very competent) observer. The only hope of even approximate homogeneity in visual data is that they should derive from single observers adequately demonstrated by experience to be steady, reliable, competent, and available for different kinds of tests over essentially unbroken stretches of time. From the standpoint of visual theory, not even for engineering purposes can one really know what kinds of measures of visual capacity to average and with respect to which to discuss variances and the like, until the nature of the basic underlying organic situation has been made understandable.

At the moment, we are concerned with the question of the seeing-frequency function. It is highly important to obtain data revealing the general form of this function. Its exact nature can only to a limited extent be ascertained by tests of curve fitting. Much more revealing information is to be obtained by attention to the questions, "How many parameters are required for this function?", and, "Do the measureable properties of these parameters favor the conception that they are physically reasonable?"

In 1921 Svedberg and Anderson described a careful experiment in which a good approximation to a uni-disperse monolayer of small silver halide grains randomly arranged without overlaps was exposed to steps of radiation energy. The limiting theory for such a situation, in terms of the then comparatively novel conception of the particulate nature of light, held that by means of correlation between the fraction of grains rendered developable by exposure to the administered radiant energy it could be determined from ordinary probability considerations how many quanta were absorbed to make such grains developable. The probability theory relevant to this case, if light should be demonstrably quantized, required that frequency of affected grains should adhere to a Poisson integral in terms of energy exposures. This was found; for this emulsion the reduction of a grain required the absorption of no more than 1 quantum. The experiment has been repeated (Webb), and the result confirmed. For less specialized, non-homogeneous emulsions, as is well known, the blackening of a photographic plate (in terms of exposure-time or of intensity) is a log Gaussian integral, or even a complex of two such integrals in certain cases.

It is clear that the retina, let alone the rest of the visual system concerned in the reporting of threshold discriminations, is not likely to find a model in a uni-disperse monolayer. Yet since 1931 a number of proposals have been made to the effect that, in view of the small average number of quanta received in a small, brief image for threshold arousal of vision, the necessarily Poisson (quantal) fluctuation in the number of quanta delivered by repeated flashes of the same mean intensity should be reflected in the flucuations of positive visual responses. On this basis, it was proposed by Hecht in 1941 that the number of quanta required for the elementary visual act could be estimated by finding the value of the Poisson parameter providing a purely inspectional fit by this function to arrays of measurements of the frequency of seeing.

It should be noted that in the meantime, in fact beginning especially in 1929 with papers by Mme. Curie and her associates, although started earlier (Crowther, 1924), a considerable body of data had arisen concerned with determinations of the sizes of genes and with the mechanism of killing (or 'hitting') small parts of organisms by X-rays and ultraviolet light. Here the procedure was to determine, from curves of percentage effectiveness as a function of exposure, the number of absorbed quanta required to produce the observed effect. In my own Laboratory this procedure was used by Arnold in 1932 to show that for monochromatic ultraviolet (λ2537), and for X-rays, the absorption of 1 quantum sufficed to inactivate a unit in the photosynthetic mechanism. To experimental biologists the method of reasoning has not been unfamiliar. The procedure can be facilitated by use of rectifying Poisson-integral plotting charts such as those devised by Campbell (1923) and discussed in detail by Frances Thorndike (1927).

Application, to the visual excitation case particularly, requires data of sufficient inherent precision and homogeneity to permit a decision regarding the shape of especially the low end of the seeing-frequency curve. As I have noted some years ago (1943), statistical criteria at least must be applied to demonstrate that there is a valid choice between, for example, a Poisson integral and a log-Gaussian; and even between a Poisson and an arithmetic $1/\Delta I$ curve. The fact is that I know of no published data on seeing-frequency which stand up under this test. The point was also made independently by J. Guild, in 1944; who adds the curious statement that a series of data in his hands (no details given) show a very high adherence to a Poisson integral with parameter $n = 17$, which is rather difficult to conceive because even with $n = 8$

the difference from a log-Gaussian is very small.

The main point, which has not been effectively tested hitherto, concerns the number of parameters present. For the Poisson, the mean and the variance are arithmetically identical; with n fixed there is just one parameter. For the log-Gaussian integral there are two parameters when the asymptotic upper limit is fixed at 100 per cent. I am aware that for certain series of published data the slope of the seeing-frequency function appears to decrease with longer exposure-times and for smaller image areas, and the like, and that some attempts have been made to deal with these changes through help from subsidiary assumptions concerning 'summation'; it seems that effective handling of these questions must await more precise data.

The procedure adopted for our tests was in most cases this: flashed were administered in groups of 5, spaced 8 to 10 seconds apart, of the same intensity in each group; the groups were spaced at least several minutes apart; 'blanks' were interspersed; the intensity levels (or exposure-time levels) were randomly presented; the percentage of response 'don't know' was always well below 3, and these 'shots' were re-run as being known predominantly due to irrelevant causes. Sitting periods were of approximately 20 minutes duration, with a rest of about 15 minutes between. Obtaining a curve required usually two full days' work. The number of flashes administered was usually 100 for each point, often 125, sometimes 200, in a few cases 75. This method was carefully compared with that in which groups of 5 'shots' were administered with each flash of a different intensity. No differences were found. The usual procedure is more convenient in testing for drifts and 'runs'. The observer relayed a 'seen' effect by tapping a light key, and carefully described the appearance of each seen flash. Various functions were re-run during the course of the experiments; this established the absence of "drifts" and the presence of a high degree of stability in performance. Not once was a 'blank' flash reported seen.

The experiment was modified in another way: at various fixed mean intensity levels the exposure-time was altered in small steps. One can look on this as an additional way in which quantal differences can be administered.

I shall illustrate briefly the form of the uniocular seeing-frequency distributions obtained. The present data do not exhibit, anywhere, the kind of asymmetry on an arith-log grid such as would be favorable to the application of a Poisson summation with a small value of the parameter. I have not found a set of measurements, in the approximately 100 obtained, for which the reverse is true. Either the number of quanta required to be absorbed for the elementary visual act is fairly large, or else the quantal fluctuation is swamped in something else. The latter alternative is clearly supported, because it is easily shown that the standard deviation and the mean, in these distributions, are totally independent quantities. Therefore the Poisson summation is ruled out under these conditions.

The conditions and combinations of conditions have included the use of square image areas between 1.6′ on a side and 1° on a side, 28 exposure times between 0.5 sec. and 0.0003 sec., 24 wavelengths, uniocular vs. binocular presentation, different concentrations of O_2 in respired air, and foveal vs. parafoveal presentation. The total of individual presentations is between 80,000 and 100,000. It is obviously permissible, so far as concerns the form of the function, to plot in abscissa units which are fractions of the measured

S. D. of each distribution. It is clear that if this is done, the chance of the function being Poisson is vanishingly small. The chance of its being log-Gaussian is very high indeed. The demonstration that it cannot have just <u>one</u> parameter appears to be determinative against the Poisson.

In illustration, parafoveal data are cited which show that the S. D. of the seeing-frequency function, with a restricted λ of light (552 $m\mu$), is a function of exposure-time, in a way quantitatively consistent with the peculiarities of the <u>I</u>, <u>t</u> curve as previously indicated. Further, with a fixed exposure-time, it is shown that the S. D. of the foveal curves is a periodic function of wave-number. The 4 minima of this function coincide quantitatively with maxima in the recorded data of wavelength discrimination; it appears that these minimal values of S. D., which at present must be associated with the idea of minimal populations of sensory effects, cannot be definitely correlated with assertions about any proposed system of physical or psychological color primaries.

It is patent in these data that frequency-of-seeing distributions may have the same abscissa of inflection (mean), with diverse σ's; and conversely. Therein is the efficient proof that no one-parameter Poisson summation can be relevant.

This finding is reenforced by at least two other considerations, derived respectively from data on the effects of oxygen partial pressure and from data on the uniocular-binocular problem. The quite important question of image area must be dismissed here, as deserving separate discussion.

The general finding has been, with a few perhaps suggestive exceptions, that breathing "100 °/°" O_2 at sea level pressure, for not too long a period, under conditions such that disturbances of normal breathing-depth and frequency are minimal, reduces visual intensity thresholds. For brief presentation-times this is not quite the case, however; the effect of variations in $[O_2]$ is markedly less with briefer exposures.

On the seeing-frequency function the effect of varying the partial pressure of inspired oxygen is decidedly interesting, but complex. There would seem to be no possible basis on which to account for the results exhibited in terms of induced fluctuations in the physical stimulus, since it is only the observer who is affected by the pulmonary atmosphere. The uniocular seeing-frequency may have an unchanged S. D., or a very strikingly changed S. D., depending on the exposure-time. The details of this situation, involving changes in the median excitation light-intensity as well, are entirely consistent with our earlier data on $[O_2]$ and exposure-time. It is found that, without changing the log-Gaussian form of the seeing-frequency function, either the S. D. <u>or</u> the mean may be altered independently by changing the partial pressure of respired oxygen, according to the exposure-time to the light-flash. I suggest that a more complete refutation of the notion of variation in threshold intensity as being due to quantal fluctuations in the stimulus would be, for the present, rather hard to find. The details of the relation to exposure-time are important, but cannot be entered upon here.

The outline of the uniocular-binocular situation can perhaps be stated more sharply. It is well known that published statements regarding the relations between the uniocular (<u>L</u>, and <u>R</u>) and the binocular (<u>B</u>) thresholds of an observer are more or less equally numerous in three categories: <u>B</u> follows the threshold for the 'better' eye; it is in between <u>L</u> and <u>R</u>; it is lower than

either *L* or *R*. Some of the confusion here is unquestionably due to failure to distinguish cases in which *L* and *R* are close together from those in which *L* and *R* may be apart. However, conditions of exposure-time, wavelength composition, image area, or retinal location can be found, for each observer I have tested, in which *L* and *R* may be quite similar and under other conditions far apart. Examples are shown in which a variety of relationships appear for different exposure-times. The *mean* for *B* may be in between *R* and *L*, near that for the 'poorer' eye, or below that for either. The *B* S. D. varies independently of the mean.

I conclude that the various conflicting published statements respecting the relations between *B* and *R*, and *L* may very well all be correct, and that the records could even be analytically useful if only the actual data were more often printed. It must also be concluded that there is no rational basis for speaking of simple probability summation for the *B* thresholds in dealing with instances such as those shown.

IV.

The work I have outlined is by no means concluded, nor have I here stressed some of its implications for the properties of the dark-adapted visual system. It is now being extended in several directions, for example to the use of subdivided or multiple target images. There is reason to expect that there will be a zone of small exposure-times below which, with small images, the logarithmic summation *must* fail. We are now in position to explore exposures much shorter than 10^{-4} *sec*. Again, we have begun to explore carefully the time-intensity and the arousal-frequency functions for single electrical pulses exciting the visual phosphenes, down to 10^{-6} *sec*. Such parallels as may emerge should be suggestive.

It is entirely possible that under some conditions of observation, such as could be significant for one or another very practical matter, it will be found that seeing-frequency curves in $\log \Delta I_0$ or in $\log t_{exp.}$ are definitely skewed at the low-frequency end, even with large numbers of presentations, and that defendable Poisson descriptions can be used. It will even then be necessary, however, to prove that the distribution is not in fact a compound one; and particularly that a *single* parameter suffices. Such compound distributions have been produced in the dark-adaptation contour.

It has been indicated that there are to be expected conditions under which it must be foreseen that the log-Gaussian summation must fail. It would be surprising indeed if it should be found that these conditions are the same for different observers. In event of the clear failure of logarithmic summation, what form should the seeing-frequency function exhibit? Should it be one in which the data follow a normal Gaussian function in $\Delta I_{\hat{0}}$; or should $1/\Delta I_{\hat{0}}$ be a more appropriate abscissa? A case can be made out for each. This matter awaits analysis.

At the moment, there appears to be good evidence showing that quantal fluctuation in the light-content of the stimulus is somehow swamped in the biological flux whereby dark-adapted visual thresholds are determined. I find no real evidence to the contrary in previously published work. The log-Gaussian integral efficiently describes the seeing-frequency data shown; its two parameters are required, and are proved to be independently modifiable. The properties of these two parameters, in terms of exposure-time, are found to be

consistent with those required by independent, homogeneous, evidence from time-intensity and dark-adaptation contours. In terms of wavelength, they are consistent with the data of hue-discrimination. For such data a Poisson integral is just not applicable.

The problem remains as to <u>why</u> the quantal fluctuations in the repetitive flash presentations appear to have their effects swamped out. One of several possible answers, not mutually exclusive, is, of course, that the essential properties of visual threshold discriminatory experience are not really determined at the retinal level at all.

DISCUSSION:

Dr. Blackwell reported recent results, which he has obtained, corroborating very closely the results included in Dr. Crozier's report. In the first place, intensity discrimination thresholds for point sources of light presented in the fovea have been studied for various restricted spectral bands. The slope of the psychometric function has been determined as a function of the dominant wavelength of the light used. The change in sigma as a function of wavelength, shown by Crozier, was well corroborated by the results obtained.

Dr. Blackwell also commented on the general question of the shape of the psychometric function which Dr. Crozier has called the "seeing-frequency function". He commented that recent studies have shown that data from some observers are adequately expressed by the cumulative normal distribution, whereas data from other subjects were adequately described by the cumulative logarithmic normal function. Dr. Blackwell mentioned that to date no hypotheses are offered to account for the apparent difference between individuals. He suggested that the precision of the data obtained makes it unambiguous, that the difference does indeed occur and is an individual affair rather than a function of the stimulus characteristics.

Dr. Blackwell described recent analyses which showed that it was mathematically impossible to discriminate between normal cumulative functions, logarithmic normal cumulative functions, Poisson functions, or indeed, the "three straight line function" proposed by Stevens, Morgan, and Volkman, on the basis of data from a single day. In order to obtain any adequate discrimination between the various theoretical curves, it is necessary to average the results obtained in separate sessions. Theoretically, this average is supposed to be unallowable. Dr. Blackwell reported experimental data indicating that data obtained on different days represents samples from the same universe and that the data justify averaging results obtained on different days. Only because the data in his study represent large numbers of observations is it possible for the various theoretical functions to be differentiated between. Dr. Blackwell also reported that the classical "yes-no" procedure of collecting threshold data can be shown to result in distortions of the shape of the psychophysical curve under some conditions.

In summary, Dr. Blackwell concluded that there was no evidence for the Poisson function in any of the data he has collected, representing absolute thresholds and difference thresholds, representing various sizes of

stimuli, and representing monocular and binocular vision. The case originally studied by Dr. Hecht, involving absolute threshold for selected wavelengths for very short durations, has not, however, been studied, and there is reason to believe that under these circumstances the shape of the function will be at least partially determined by quantum considerations. In addition, it would seem necessary to assume certain variations in sensitivity with time which will tend to normalize the Poisson functions based upon quantum assumptions alone.

Dr. Wald commented upon the role of the shape of the seeing-frequency function in the Hecht discussion of the quantal requirements for vision. Dr. Wald prepared a statement of his remarks for inclusion in the Proceedings. The statement is presented below:

FREQUENCY-OF-SEEING MEASUREMENTS AND POISSON FUNCTIONS - by George Wald

We have lately witnessed a considerable development based on the fitting of frequency - of - seeing functions with the Poisson equation. The particular interest in this operation is that it is believed to yield important evidence on the number of quanta involved in visual excitation. One can only be grateful for Professor Crozier's discussion and measurements, and for the remarks of Dr. Blackwell in introducing a much needed skepticism into this province. I think however that it is of prime importance to keep intact the argument dealing with quantum relations at the visual threshold and to evaluate the limitations of the Poisson analysis within this wider context.

The quantal analysis of the minimal threshold of human vision introduced by Hecht, Shlaer and Pirenne several years ago (J. Gen. Physiol., 25, 819, 1942) started from the realization that a flash containing some 50 - 150 quanta of blue-green light incident on the cornea of the eye can just be seen. This came out of their own measurements, and agreed also with previous measurements made by a number of observers over a long period of years. From fairly reliable estimates of corneal reflection, transmission of the ocular media, and density of absorption of rhodopsin in the retina, it is possible to come directly to the conclusion that only about one-tenth of the quanta incident on the cornea are actually absorbed by the rhodopsin of the dark adapted rods. Since these 5 - 14 quanta may be absorbed in an area containing some five hundred rods and still be seen, it is extremely probable that each individual rod is excited by the absorption of a single quantum. That is, from this direct analysis of experimental measurements one can conclude that one quantum absorbed by rhodopsin is sufficient to discharge a rod; and that 5 - 14 such elementary acts occurring simultaneously are sufficient to produce the minimal visual sensation.

This is a fundamentally important datum that has large consequences for visual theory. It also has important consequences for the frequency - of - seeing function which Professor Crozier has discussed. The converse however is not true. Neither the vagaries of frequency - of - seeing data nor their mathematical treatment reflects in any way upon these direct measurements. The mathematical analysis of frequency - of - seeing functions has an interest of its own; but it is important to keep the direct estimate of the number of quanta required to stimulate vision distinct from it.

Hecht, Shlaer and Pirenne went on to point out that since so small a number of quanta is involved in the minimal threshold of vision one might expect a large fluctuation in the frequency - of - seeing function from this source alone. That is, if vision is dependent upon the absorption in the retina of a very small number of quanta (n), one can deliver this precise number only in the average case. The actual numbers of quanta absorbed per flash will vary rather widely, and this variation should be described by the Poisson distribution, $P_n = a^n e^{-a}/n!$, in which P_n is the probability that a flash will yield the required n absorbed quanta, and a is the average number of quanta per flash. One therefore expects to find some correspondence between the Poisson distribution and the frequency-of-seeing function; and indeed a comparison

of these might yield independent information on the number of quanta (n) concerned in the visual response.

Hecht, Shlaer and Pirenne showed that the frequency - of seeing function does in fact have a shape resembling the Poisson integral, and that the fitting of the Poisson equation yields a number (n) of about 5 to 8. This is therefore in good agreement with the direct estimate of the number of quanta involved in the minimal visual excitation.

What concerns us here is the realization that in this argument the Poisson analysis holds an auxiliary position. It cannot stand by itself. It is in fact implicit in this argument that the frequency - of seeing data cannot represent a simple Poisson function. Let us consider this point for a moment.

If fluctuations in the delivery of a small number of quanta were all that one had to deal with at the threshold one might indeed expect to obtain a genuine Poisson function from frequency - of - seeing measurements. It is clear however that superimposed on such a Poisson function in all experiments, however refined, are other distribution functions due to variations introduced by the apparatus and by the observer.

Both types of such ordinary experimental variations have the effect of pulling out the frequency - of - seeing function on the intensity axis, and of yielding on application of the Poisson equation lower values of (n). That is to say, the cruder the apparatus and more variable the subject, the smaller value of (n) is obtained by Poisson analysis of the frequency - of - seeing function.

The possibility of discovering in this way that very few quanta are needed for visual excitation has already been exploited. Van der Velden has urged a 2-quantum theory of excitation as an advance on Hecht's conclusion that some five to fourteen quanta are needed. Van der Velden (Physica, 11, 179, 1944; Ophthalmologica, 111, 321, 1946; cf. also J. Opt. Soc. Amer., 37, 908, 1947.) bases his 2-quantum theory entirely upon the evaluation of constants in statistical equations applied to visual measurements. In the first instance he used the same type of Poisson analysis of the frequency - of - seeing function as was used earlier by Hecht.

I think it fair to say that van der Velden's description of his measurements contains sufficient evidence that they were considerably less refined than Hecht's. I note for example that van der Velden used instead of monochromatic light a very broad band of the spectrum; that he varied his intensities with a rheostat in series with his lamp, which of course simultaneously changed the color temperature and hence the spectral band with which he was operating; that his exposures were regulated with an ordinary photographic shutter, a notoriously undependable instrument; and that for some reason not clear to me his estimate of the absolute energies involved in the threshold excitation is lower than that of previous workers by a factor of about ten times. That is, van der Velden reports that his observers saw flashes containing an average of about 7 - 8 quanta incident on the cornea, therefore about one-tenth the numbers of quanta found by Hecht and earlier workers. I think it reasonable to believe that van der Velden found the value two for (n) in the Poisson equation primarily because his measurements involved larger errors than had Hecht's.

Indeed it seems that Hecht's group had encountered this kind of phenomenon in their own work, perhaps in even more drastic form. In Pirenne's recently published book "Vision and the Eye" (Pilot Press Limited, London, 1948) on page 95 there occurs a footnote which says "It may be noted that when conditions are not carefully controlled, e. g. when the observer is untrained, or tired, much shallower frequency - of - seeing curves are obtained: then large biological variations certainly occur." I wrote asking Pirenne whether considerable changes in the (n) obtained by Poisson analysis of frequency - of - seeing curves could be induced in this way. He said they could; and that he thought that in one instance with a new observer a value of (n) had been obtained *smaller than one*!

There is therefore no difficulty in obtaining *small* values of (n); the shoe is on the other foot. One needs, by refining the methods of experimentation and working with as good subjects as possible, to see how steep frequency - of - seeing functions can be found, i.e., how *large* one can find the values of (n). Even then one knows that one cannot be dealing with a pure Poisson function, for some portion of the frequency - of - seeing curve must be assigned to fluctuations in the apparatus and the observer.

Is the Poisson analysis then completely arbitrary, or does it have a place in the evaluation of frequency - of - seeing measurements? I think there is no doubt that the frequency - of - seeing function one obtains in the dark adapted eye contains within it a Poisson function, representing fluctuations in the numbers of quanta which excite vision. Poisson analysis of the whole function yields a value of (n) which may be too small; but it cannot be too large. That is, if we were able to take out of the frequency - of - seeing function the components due to ordinary experimental variations we should have left a *steeper* function representing the genuine Poisson distribution. From this we would obtain *larger* values of (n) in the Poisson equation. The values of (n) we obtain by fitting frequency - of - seeing functions directly with the Poisson function therefore represent the *lowest limits* that can be assigned to the numbers of quanta concerned in the visual response. The actual numbers of quanta may be considerably greater.

Here however we must consider again the direct measurements. They set an *upper limit* of about 5 - 14 to the number of absorbed quanta needed to excite vision. This taken together with the lower limit of five to eight yielded by the Poisson analysis leaves the whole argument in a satisfactory condition.

One can formulate this argument in another and I think preferable way. Having once found by direct measurement that only about 5 - 14 quanta are involved in the minimal threshold, one can proceed to invoke the Poisson relation, setting these numbers for (n) in the Poisson equation. This amount of variation *must* be included in the frequency - of - seeing function purely on a quantal basis. One can then ask how well this predicted variation agrees with the observed frequency - of - seeing measurements. One expects the frequency - of - seeing function to be somewhat broader than such a Poisson integral; the discrepancies between them represent the ordinary experimental variations introduced by apparatus and subject.

Did Hecht himself intend his use of the Poisson function to be understood in this fashion? I think he did; witness his discussion of the interrelations of biological variation and physical fluctuation in his papers (J. Opt. Soc. Amer., 32, 1942, page 48; J. Gen. Physiol., 25, 1942, page 836).

So when Professor Crozier and Dr. Blackwell say that a sufficiently accurate frequency - of - seeing function departs from the Poisson integral, I am sure they are right. Nevertheless the frequency - of - seeing function must contain the Poisson integral, as shown by the direct demonstration that only a small number of quanta - some 5 - 14 in all, and only one per rod - is involved in the minimal human threshold. The Poisson function, however, is overlaid and distorted by the ordinary experimental variation; and this must have been true for Hecht's own measurements as for all others.

Everyone has heard the remark that inside of every fat man there is a thin man crying to be let out. Just so inside of every frequency - of - seeing function - at least at the minimal threshold - there is a Poisson integral crying to be let out.

In response to Dr. Wald's remarks,

Dr. Crozier stated his belief that Dr. Hecht had attached a great deal of significance to the shape of the psychophysical function. Also, Dr. Crozier felt that the critical question was whether or not the Poisson function was indeed obtained under conditions of careful control where there was no question of obvious spurious variability.

Dr. Crozier also remarked that ridiculus conclusions have been reached in the literature on the curve-fitting of psychometric functions. For example, Guild reports good differentiation between a Poisson of 17 and a logarithmic normal distribution. Dr. Crozier pointed out that such deviation is mathematically impossible because of the near equivalence of these two functions.

Dr. Grether asked whether the observers in Dr. Crozier's experiments reported the colors seen in short flashes of chromatic light.

Dr. Crozier replied that, particularly in short exposures, observer reports as to the color of a chromatic stimulus were exceedingly variable. He stated that the observer will report with confidence every color from the spectrum at some time when the actual stimulus is every other color. The highest frequency of color seen corresponds to the wavelength of the stimulus light, but the variability observed is apparently enormous. For example, Dr. Crozier reported confident responses of blue and brown color from a nearly monochromatic red stimulus.

Dr. Dimmick asked whether there was any basis of discrimination between those instances in which logarithmic normal and those in which normal cumulative functions were obtained.

Dr. Crozier reported that at the present time the exact relationships were not known, but that he was sure that under the right conditions of exposure intensity, etc., either of the two functions might be obtained.

ATMOSPHERIC ATTENUATION OF BRIGHTNESS CONTRAST ALONG A HORIZONTAL PATH FOR THE VISIBLE RANGE OF THE SPECTRUM

Howard S. Coleman
University of Texas

ABSTRACT

A field study of atmospheric attenuation of brightness contrast is being conducted by the Physics Branch of The Office of Naval Research at The University of Texas. The purpose of the study is to provide physical data needed to determine the "visibility" of objects for such weather conditions as are encountered in military and civil situations. The attenuation measurements consist of the determination of the apparent brightness of plane black targets and plane white targets located at different distances from a Photoelectric Telephotometer. The targets used subtened the same angle (1.86 minutes) with respect to the Telephotometer. Seven black and seven white targets are used. These vary in size from 0.65 x 1.30 to 33 x 66 feet in size and are located at ranges up to 15267 yards. Atmospheric attenuation of brightness contrast measurements have been made through the atmosphere for different transparency conditions including through light rain, light snow, and dust. The results of these measurements indicate that the apparent contrast, C_R, of an object having an inherent contrast of C_0, and located at a range, R, from the Telephotometer, is given by $C_R = C_0 e^{-BR}$, where B is a constant, referred to as the attenuation coefficient.

INTRODUCTION

The Physics Branch of The Office of Naval Research is conducting a field study of the attenuation of brightness contrast by the atmosphere. This study was started in February 1947 at The Pennsylvania State College as a part of Task IV of Contract N6onr-269 and is being continued at The University of Texas (starting in February 1948) as a part of Task IX of Contract N6onr-266. The work at The Pennsylvania State College consisted primarily in the design and construction of a Photoelectric Telephotometer. In addition some progress was made toward the determination of the field requirements of the study. The Telephotometer was transferred to The University of Texas in April 1948, and the design of the required field installations started. The design of the field installations was completed in June 1948 and the construction work started. Although some of the construction operations are still incomplete (March 1949), a sufficient fraction of the installations were completed by September 1948, to start making experimental measurements at that time. It is the purpose of this report to describe field installations and to present samples of the preliminary atmospheric attenuation data obtained. In describing these data, the definitions used have been summarized on Drawing D-6008.

THE APPARATUS

The field installation used in the studies of atmospheric attenuation of brightness contrast by The University of Texas is located approximately five miles east of Austin, Texas, in the Colorado River area as shown on Photograph P-5159. The installation includes a Photoelectric Telephotometer and a series of plane black objects and white objects, referred to as targets, arranged as shown on

Drawing D-6021. Seven pairs of black and white targets are used in the field study. These vary in size from 0.65 x 1.30 to 33 x 66 feet, and are located at distances ranging from 300 to 15267 yards from the Telephotometer. The forms of one of the smaller targets and the largest target are shown on Photographs P-5150 and P-5151, and Drawing D-6018. The black targets are holes leading into black boxes, and the white targets are plane objects painted white. The design of the black targets was intended to minimize changes of inherent brightness that occur with changes in the azimuth of the Sun. The appearance of the targets viewed from the Telephotometer is shown on Photograph P-5149. In this photograph one target, No. 0, is shown. This target is used only for checking the apparatus. It is also evident that Target No. 6 is incomplete.

The Telephotometer is housed as shown on Drawing D-5033 and in Photograph P-5130. The details of the Telephotometer are shown schematically on Drawing D-5676 and on Photograph P-5146. The Telephotometer has a highly linear response to brightness as shown by Drawing D-6009. The spectral response of the photoelectric tube in the Telephotometer is shown on Drawing D-6010. Since the results of the atmospheric attenuation measurements are likely to be to predict the visibility of objects using the human eye as a photosensitive receptor, a special filter has been provided which renders the spectral response of the Telephotometer closely the same as that of the human eye. This is shown on Drawing D-6011. From a physical point of view, the attenuation of brightness contrast for specified spectral regions is of interest. For this purpose a series of four interference filters has been provided in the Telephotometer which limit its spectral range practically to four monochromatic regions of the visible spectrum. These filters have been designated as "violet", "blue", "green", and "red", the spectral transmittance of which are shown on Drawings D-5970, D-5971, D-5972 and D-5973.

Commercially available illumination meters are used to measure the target illumination when such measurements are needed.

THE PROCEDURE

The procedure used to make atmospheric attenuation of brightness contrast measurements consists simply of measuring the apparent brightnesses of the black and the white targets using the brightness of the horizon as a basis of comparison. Since the calculations of brightness contrast are simplified somewhat by using a numerical value of the horizon brightness some such figure as 10, 100, or 1000, the Telephotometer is adjusted such that its response is one of these figures (usually 100 is used) when it is directed toward the horizon. In making this adjustment, however it is important to use the same part of the horizon each time as its brightness varies with azimuth and elevation. The variation in brightness with elevation is shown on Drawing D-5042. In addition it is to be noted that the contributions of the light scattered by the atmosphere (referred to hereafter as Air Light) to the horizon brightness are not likely equal for equal distances along the target range as shown by Drawing D-6007.

THE DATA

The data obtained in the study of attenuation of brightness contrast by the atmosphere are in the form of apparent brightness measurements of the black targets and the white targets, using the horizon brightness as a basis

for comparison. These brightness values are used to calculate the apparent contrast using the defining equations shown on Drawing D-6008.

A graphical method is used in reducing the atmospheric attenuation data. Samples of these are shown on Drawings D-6022, D-5907, and D-5912. These drawings in general show that the data for the black targets fall in a straight line under almost all conditions of the weather and illumination along the line of sight.

Samples of the basic data for the white targets are shown on Drawings D-5907 and D-5912. When these are plotted in the same manner as the black targets, the data often do not fall on a straight line. This has been found to be related to the differences in illumination at the individual targets. Samples of these differences, as a function of time, are shown on Drawings D-6027 and D-6028. If corrections are made for these variations in illumination at the different targets, as shown on Drawing D-6023, the data have been found to fall close to a straight line as shown on Drawing D-6014. In this connection, it might be noted that the preliminary data show that the slopes of the lines for the black targets and the white targets are the same for any one set of atmospheric conditions. In addition to the samples of data obtained in The University of Texas program, two samples have been included of the data obtained at The Pennsylvania State College at State College, Pennsylvania, during the development stages of the Telephotometer. These are shown on Drawings D-5081 and D-5074. It is evident that similar results are obtained for the two locations.

The samples of data described above were obtained using the filter rendering the spectral response of the Telephotometer similar to that of the human eye. From a basic point of view, however, a knowledge of the attenuation of brightness contrast for specific wavelengths is of more value. Samples of the attenuation of brightness contrast for four different effective wavelengths are shown on Drawing D-6038.

In as much as it is intended to explore possible correlations of atmospheric attenuation data with the meteorological elements as normally recorded by weather stations, data are obtained for the periods in which the atmospheric attenuation measurements are made from two weather stations located in the vicinity of the field installation. These two weather stations are located at the Austin Municipal Airport and the Bergstrum Army Air Base as shown on Photograph P-5159. Samples of the meteorological data obtained from the two weather stations together with the Meteorological Range measured by means of the Telephotometer are shown on Drawings D-5996 to D-6006 inclusive.

In making the atmospheric attenuation of brightness contrast measurements, one important variable which is not easily described is the type and extent of clouds covering the sky. In order to obtain a fairly accurate description of the cloud coverage, a device has been developed, referred to as the Sky Coverage Recorder (abbreviated to S.C.R.). This device together with a sample of a record of the sky coverage is shown on Photograph P-5156.

DISCUSSION AND CONCLUSIONS

It is evident from the material presented in this report that the atmospheric attenuation of brightness contrast can be measured with considerable precision using the apparatus and procedures described. While insufficient data have been accumulated to arrive at any final conclusions, certain observations can be made at this time. These are:

1. It is evident that if proper allowances are made for variation and illumination along "the line of sight", Koschmieder's law for Attenuation of Brightness Contrast by the Atmosphere holds for both black targets and white targets for a variety of weather conditions.

2. The attenuation coefficient appears to be relatively insensitive to changes in illumination along "the line of observation", as is indicated from the data obtained for the black targets.

3. The atmospheric attenuation data collected to date (March 1949) show very little correlation with the meteorological elements ordinarily recorded at Government Weather Stations.

4. It is evident that the atmospheric attenuation coefficient is a function of wavelength. In this connection the preliminary data indicate that the attenuation coefficient is less for "red" light than for "violet" light.

DISCUSSION: (Subcommittee meeting, March 3, 1949)

Mr. Middleton expressed his surprise in the applicability of Koschmieder's law for dark targets when there was partial cloud cover. He asked Dr. Coleman if a departure from Koschmieder's law would not be expected when there was non-uniform illumination along the airpath.

Dr. Coleman agreed that a breakdown of Koschmieder's formulation would be expected and that the apparent applicability surprised him also.

Mr. Middleton expressed interest in the apparent absence of correlation between Beta and relative humidity. He expressed his belief that the humidity data would prove a good predictor of Beta provided concomitant measurements were made of nuclei counts.

Mr. Middleton asked Dr. Coleman to what extent Beta was dependent upon the wavelength of light utilized, in terms of an exponent.

Dr. Coleman answered that he could not give quantitative results since the data obtained with selected spectral regions were obtained just prior to the time of the meeting.

Mr. Middleton also commented that he believed the exponential law expressed in terms of contrast should be called "Duntley's law" rather than "Koschmieder's law."

Dr. Duntley asked whether there was any correlation observed between Beta and wind velocity. He remarked that such a correlation appeared to exist in the preliminary tests conducted at the Tiffany Foundation.

Dr. Coleman stated that no such correlation was observed in the University of Texas studies. He explained the apparent difference between the Texas results and the Tiffany results on the basis that at Tiffany the presence or absence of city polution was a very important determinant of the value of Beta. Wind velocity was a good determinant of whether or not city polution was blown across the path of sight.

Dr. Neuberger questioned whether significant amounts of dust were produced with high wind velocities at the Texas installation. He also expressed his belief that a good correlation would be obtained between relative humidity and nuclei count and Beta, especially with values of relative humidity greater than 70%.

Dr. Duntley referred to the table of Dr. Colemsn's results relating measured meteorological range and the predictions made by meteorological observers. He reported that Douglas had found observed meteorological range to be three-fourths of the true meteorological range.

Dr. Duntley reported that Mr. Lane at the Tiffany Foundation apparently also estimated meteorological range at about three-fourths of the value measured by the Douglas transmissometer. Although the average value was very nearly three-fourths, the correlation between the observed and measured meteorological range was not very good.

Dr. Coleman commented that one couldn't expect to obtain very good correlation between observed and measured meteorological range under the conditions used at the average meteorological station with variations in the size of the range marks and the contrast of the range marks against the sky.

Dr. Hulburt commented that the three-fourths figure may merely mean that the contrast threshold of the eye is more nearly 0.055 than 0.02 as assumed by the Koschmieder formula.

Dr. Coleman agreed that the contrast threshold might be as high as 0.055, but expressed his belief that the increased threshold was probably occasioned by the reduced size of range marks rather than by an increased limiting threshold for the human eye.

Mr. Douglas emphasized the importance of the exact criterion of visibility used in estimating visual ranges. He felt that the difference between detection and recognition thresholds might very nearly make up for the differences being discussed.

Dr. Blackwell commented on the fact that the threshold of the eye for large objects, under laboratory conditions of response, is considerably smaller than 0.01, but that when the observer is permitted to judge the limit of visibility, his threshold may go to two or five times this value, depending upon personal variables. It is thus possible that the differences are merely representative of the levels at which the visibility criteria are set by the observer.

Commander Brown questioned whether or not it is possible for more adequate visibility range marks to be employed at meteorological stations than those at present used.

Mr. Harrison stated his opinion that it was more important to introduce instruments in the meteorological stations than to improve the conditions of visual range determination. He stated his opinion that instruments would be added to meteorological stations within the next two years.

DISCUSSION: (Vision Committee Meeting, March 5)

Mr. Harrison emphasized the importance of extending Dr. Coleman's work to include determinations of Allard's law relating the attenuation of light by the atmosphere to distance, at night. He expressed his belief that relatively minor additions to Dr. Coleman's equipment and personnel would make this expansion of the work possible.

Mr. Harrison questioned whether the Vision Committee could recommend such an extension of Dr. Coleman's research.

Dr. Coleman stated that although the original plan of research did not include studies of Allard's law, extension to cover this aspect of atmospheric transmissivity could be made.

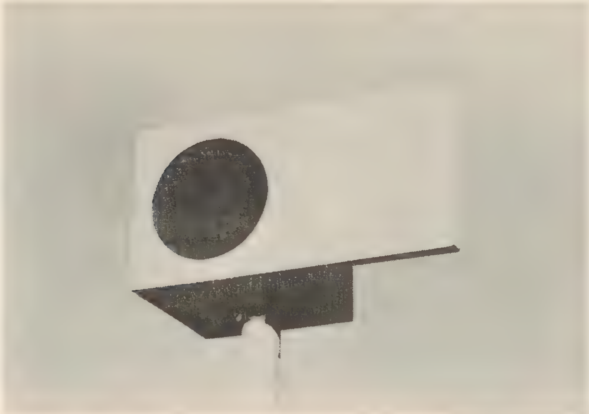
Mr. Middleton expressed his belief that studies of atmospheric transmission should be made, particularly at short visual ranges such as those encountered in fogs. He emphasized the importance of studies of the effect of aperture of light source and of photographic receiver.

After considerable discussion the following resolution was approved by the Vision Committee:

THE VISION COMMITTEE EXPRESSES ITS CONFIDENCE IN THE STUDIES OF ATMOSPHERIC ATTENUATION BEING UNDERTAKEN BY PROFESSOR HOWARD S. COLEMAN, AT THE UNIVERSITY OF TEXAS, AND EXPRESSES ITS HOPE THAT THE WORK CAN BE CARRIED TO CONPLETION. IN VIEW OF THE IMPORTANCE OF THE ADDITIONAL INFORMATION, THE VISION COMMITTEE RECOMMENDS TO THE OFFICE OF NAVAL RESEARCH THAT CONSIDERATION BE GIVEN TO BROADENING THE SCOPE OF THE STUDIES IN ATMOSPHERIC OPTICS, BEING CONDUCTED BY PROFESSOR COLEMAN, TO INCLUDE POINT SOURCES OF LIGHT AND VISUAL RANGE OBSERVATIONS AT NIGHT, ASSOCIATED WITH A STUDY OF THE SIZES AND CONCENTRATION OF SUSPENSOIDS AND PRECIPITATION INVOLVED.

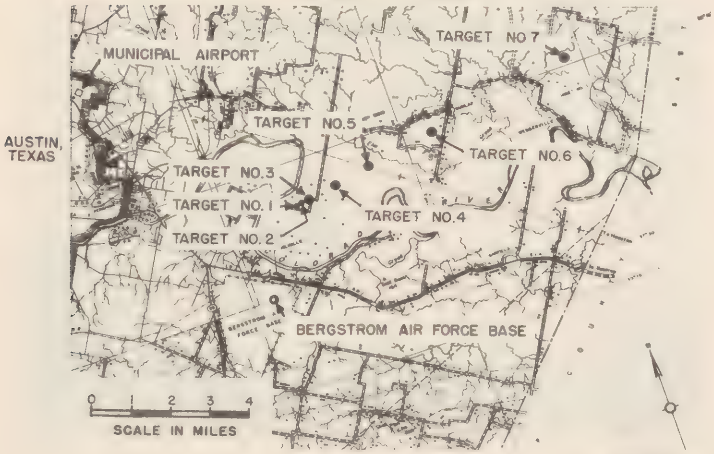
UNIVERSITY OF TEXAS VISIBILITY TARGET NO. 2

TARGET SIZE - 1.05 FT. X 2.1 FT. TARGET RANGE-494 YARDS



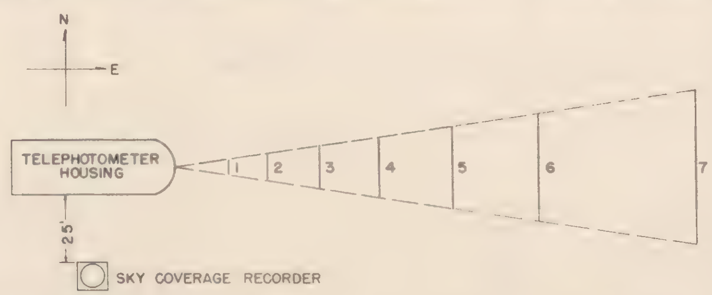
ORL/UT
19 FEBRUARY 1949
P-5150

MAP SHOWING LOCATION OF UNIVERSITY OF TEXAS VISIBILITY TARGETS



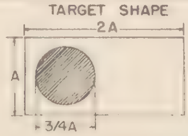
ORL/UT
22 FEBRUARY 1949
P-5159

SCHEMATIC DIAGRAM SHOWING THE ARRANGEMENT OF THE APPARATUS USED IN THE UNIVERSITY OF TEXAS ATMOSPHERIC OPTICS PROJECT



TARGET NO.	TARGET SIZE	TARGET RANGE
1	0.65 FT. X 1.3 FT.	300 YDS.
2	1.05 FT. X 2.1 FT.	494 YDS.
3	2.4 FT. X 4.8 FT.	1109 YDS.
4	4.6 FT. X 9.2 FT.	2167 YDS.
5	9.2 FT. X 18.4 FT.	4153 YDS.
6	16.4 FT. X 32.8 FT.	7628 YDS.
7	33 FT. X 66 FT.	15267 YDS.

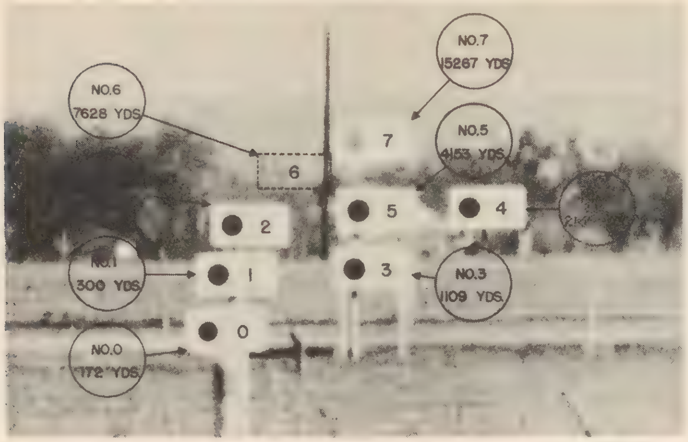
TARGET SHAPE



ORL/UT
22 FEBRUARY 1949
D-6021

TELEPHOTOGRAPH OF THE UNIVERSITY OF TEXAS VISIBILITY TARGETS AT 4:15 P.M. 11 FEBRUARY 1949

SUBTENSE OF BLACK TARGETS = 54.0×10^{-5} RADIANS (1.86 MINUTES)
METEOROLOGICAL RANGE = 56000 YARDS



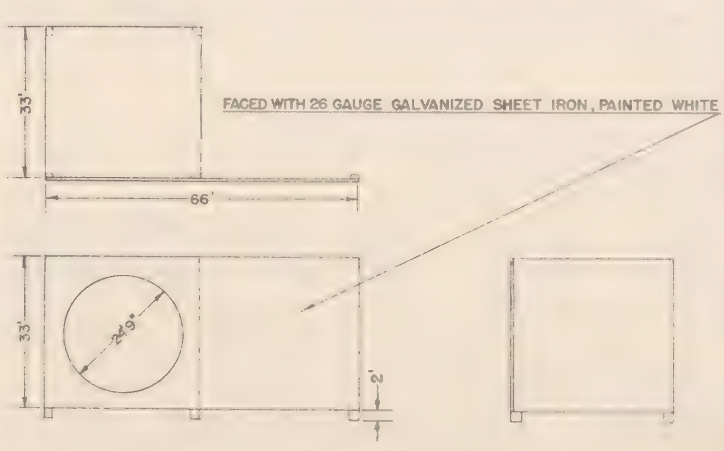
ORL/UT
11 FEBRUARY 1949
P-5149

UNIVERSITY OF TEXAS VISIBILITY TARGET NO. 7

TARGET SIZE – 33 FT. X 66 FT. TARGET RANGE – 15267 YARDS

ORL/UT
19 FEBRUARY 1949
P-5151

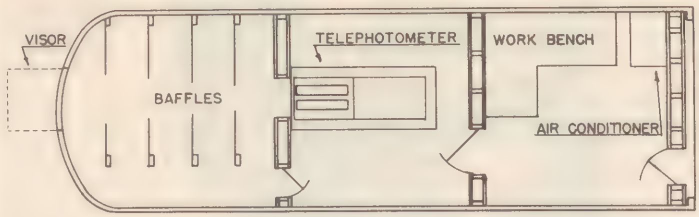
UNIVERSITY OF TEXAS VISIBILITY TARGET NO. 7



SCALE: 2" = 33'

ORL/UT
21 FEBRUARY 1949
D-6018

SCHEMATIC ARRANGEMENT OF EQUIPMENT IN TELEPHOTOMETER HOUSING
FOR ATMOSPHERIC ATTENUATION STUDIES

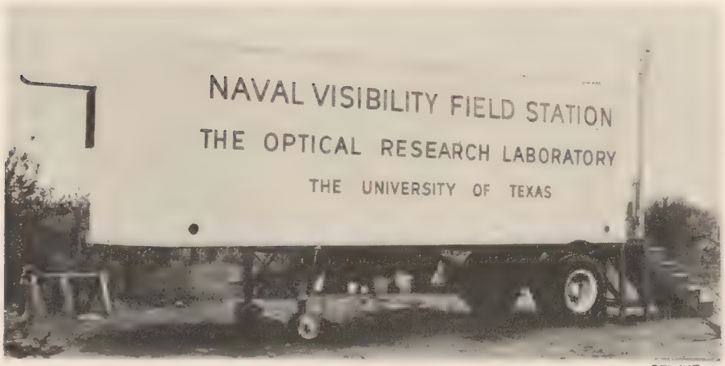


TOP VIEW

ORL/UT
10 JULY 1948
D-5033

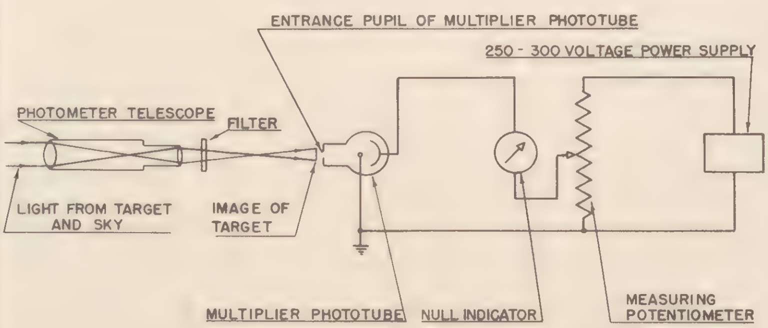
TELEPHOTOMETER HOUSING USED IN THE ATMOSPHERIC ATTENUATION
STUDIES AT THE UNIVERSITY OF TEXAS

13 OCTOBER 1948



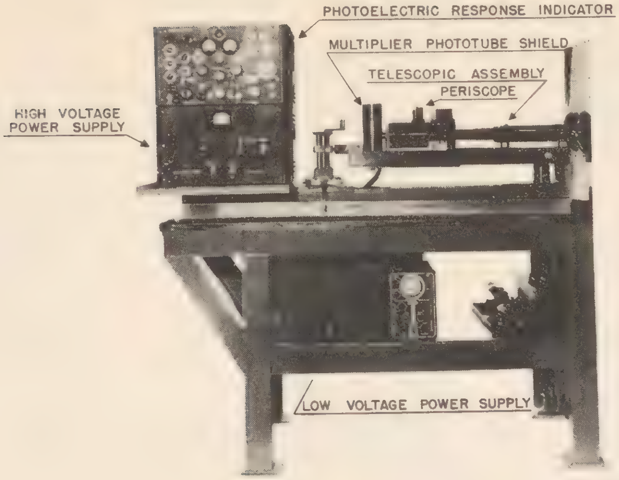
ORL/UT
30 OCTOBER 1948
P-5130

SCHEMATIC DIAGRAM OF THE PHOTOELECTRIC TELEPHOTOMETER



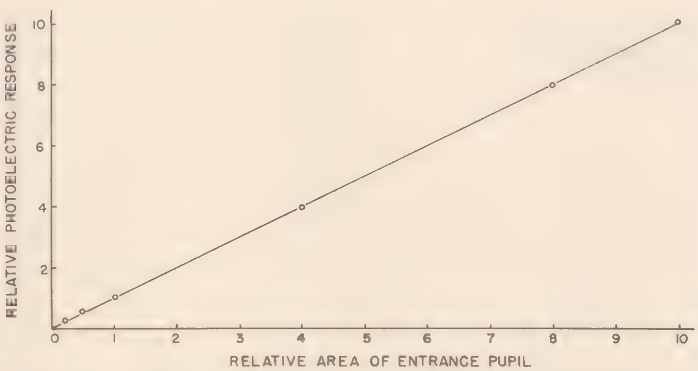
ORL/UT
5 JANUARY, 1949
D-5676

THE PHOTOELECTRIC TELEPHOTOMETER



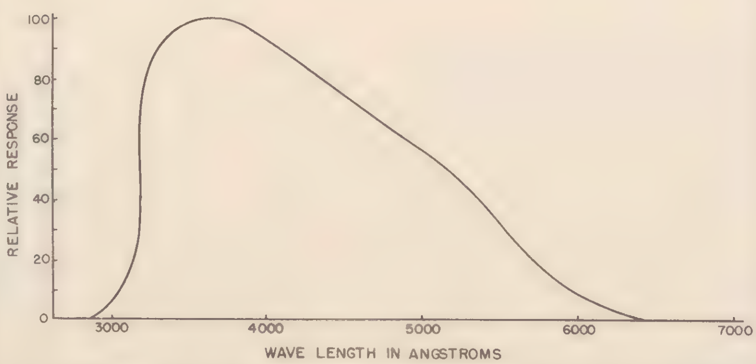
ORL/UT
25 JANUARY 1949
P-5146

DATA SHOWING LINEARITY OF TELEPHOTOMETER

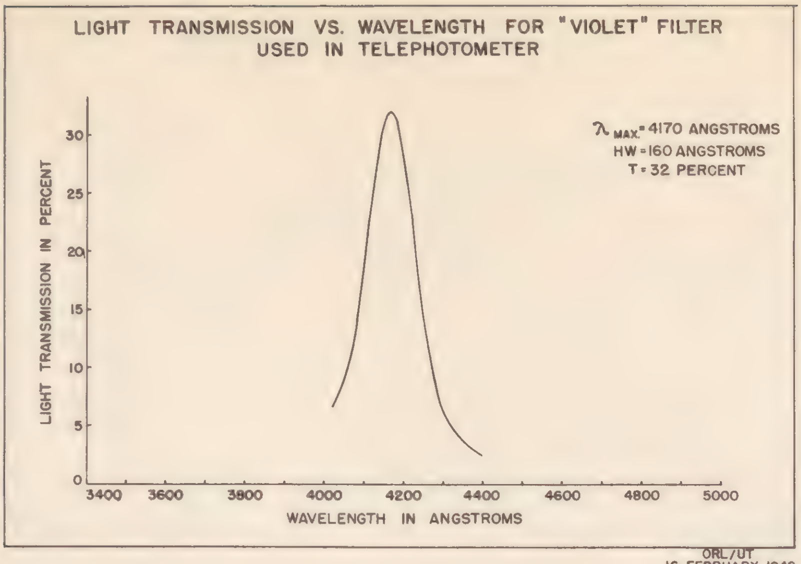


ORL/UT
19 FEBRUARY 1949
D-6009

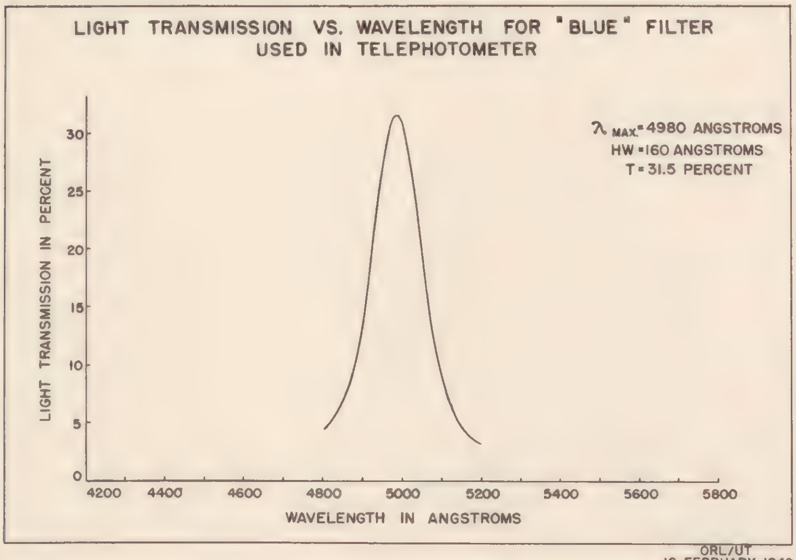
SPECTRAL RESPONSE OF PHOTOELECTRIC TUBE USED IN TELEPHOTOMETER



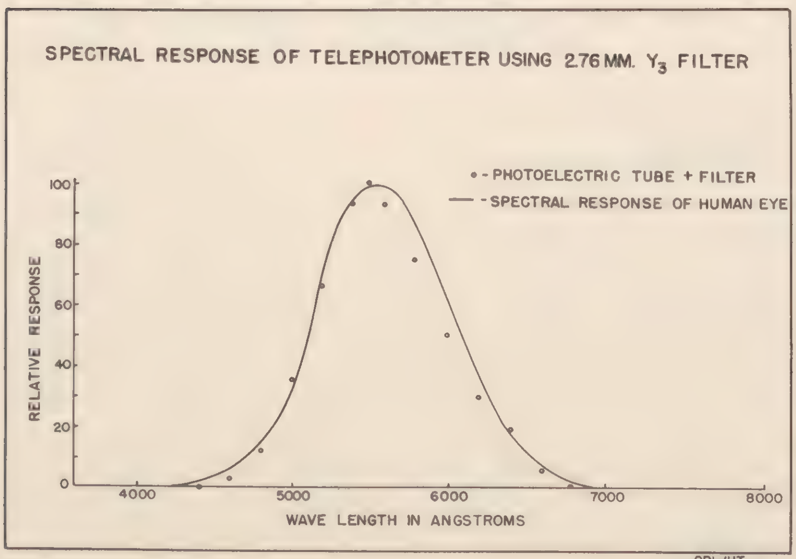
ORL/UT
19 FEBRUARY 1949
D-6010



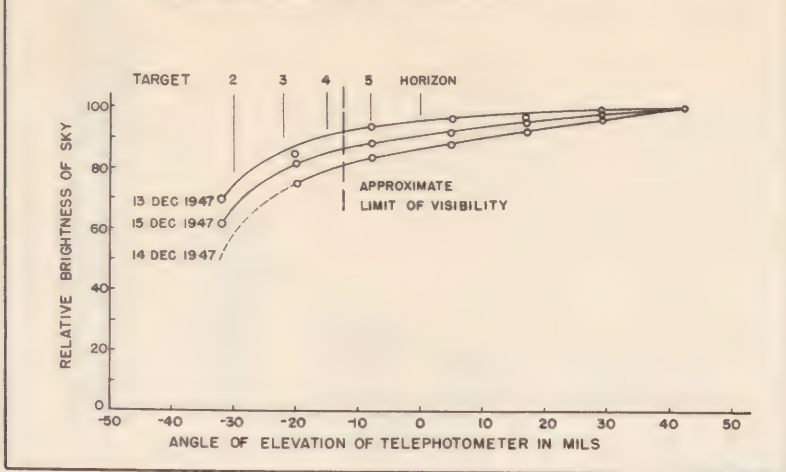
ORL/UT
16 FEBRUARY 1949
D-5970



ORL/UT
16 FEBRUARY 1949
D-5971

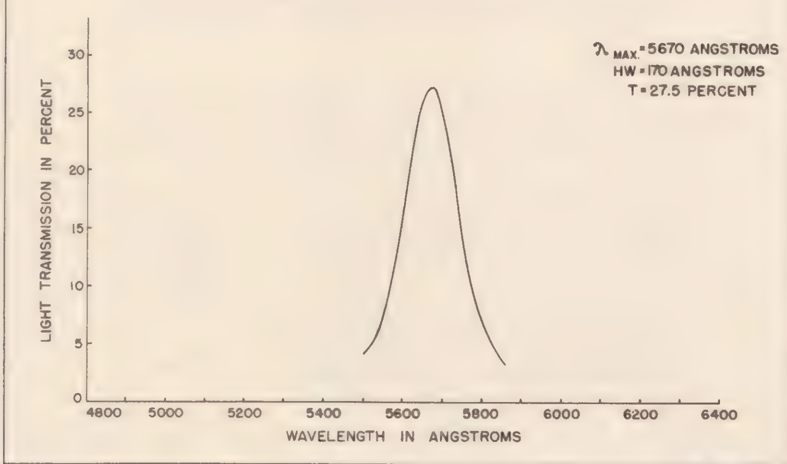


ORL/UT
19 FEBRUARY 1949
D-6011



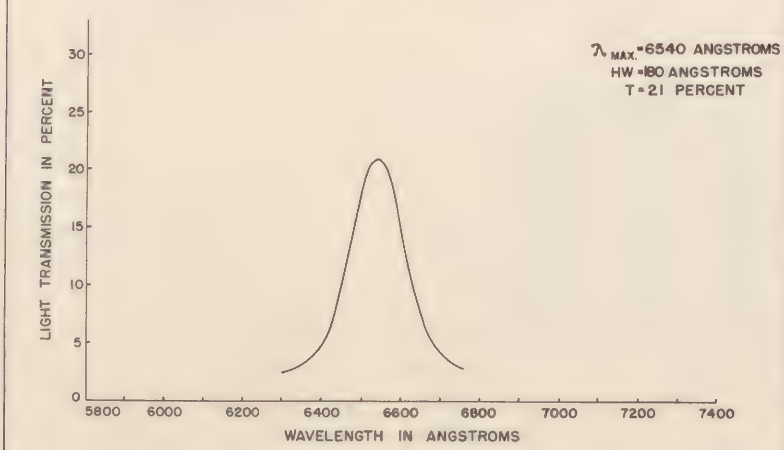
SKY BRIGHTNESS VS. ANGULAR ELEVATION AT PENN STATE DURING PERIODS OF LOW VISIBILITY

ORL/UT
28 JULY 1948
D-5042



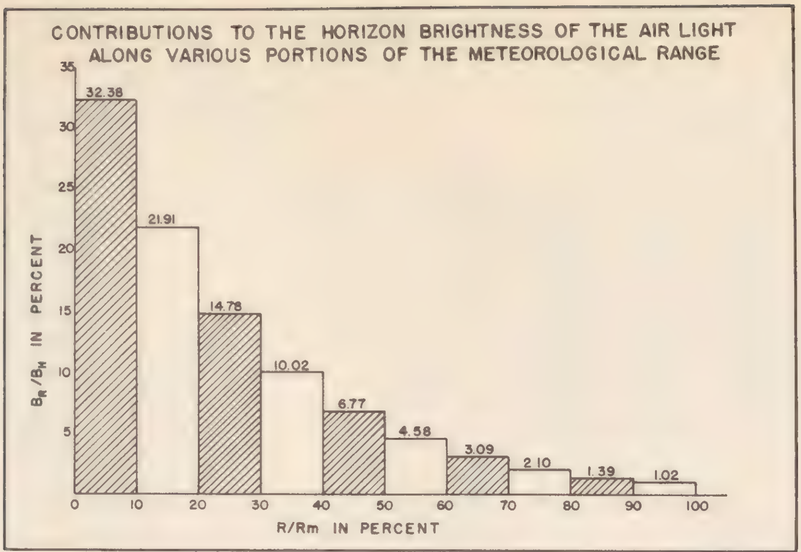
LIGHT TRANSMISSION VS. WAVELENGTH FOR "GREEN" FILTER USED IN TELEPHOTOMETER

ORL/UT
16 FEBRUARY 1949
D-5972



LIGHT TRANSMISSION VS. WAVELENGTH FOR "RED" FILTER USED IN TELEPHOTOMETER

ORL/UT
16 FEBRUARY 1949
D-5973



ORL/UT
19 FEBRUARY 1949
D-6007

DEFINITIONS AND EQUATIONS USED IN THE STUDY OF ATMOSPHERIC ATTENUATION OF BRIGHTNESS CONTRAST

(1) DEFINITION OF INHERENT BRIGHTNESS CONTRAST OF TARGET

$$C_0 = \frac{B_0 - B_H}{B_H}$$

B_0 = INHERENT BRIGHTNESS OF TARGET (AT ZERO RANGE)
B_H = BRIGHTNESS OF TARGET BACKGROUND
C_0 = INHERENT CONTRAST

(2) DEFINITION OF APPARENT BRIGHTNESS CONTRAST OF TARGET

$$C_R = \frac{B_R - B_H}{B_H}$$

B_R = APPARENT BRIGHTNESS OF TARGET AT RANGE R
C_R = APPARENT CONTRAST

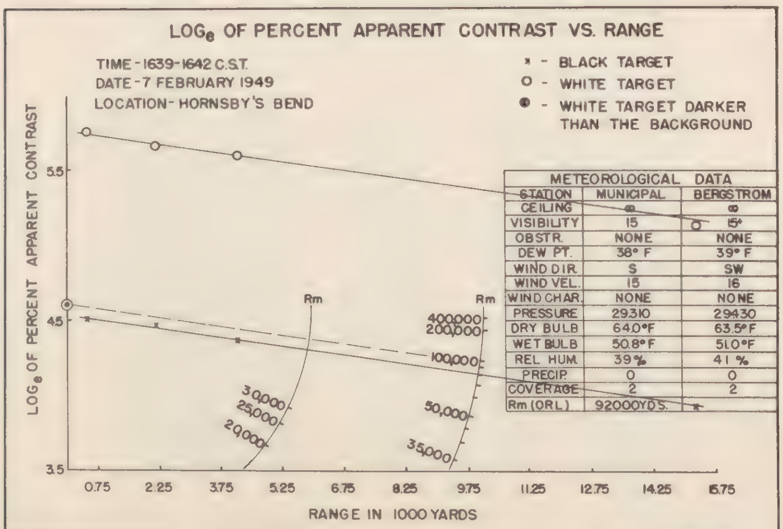
(3) KOSCHMIEDER'S LAW

$$C_R = C_0 e^{-\beta R}$$

$$C_R = C_0 e^{-\frac{3.912 R}{R_M}}$$

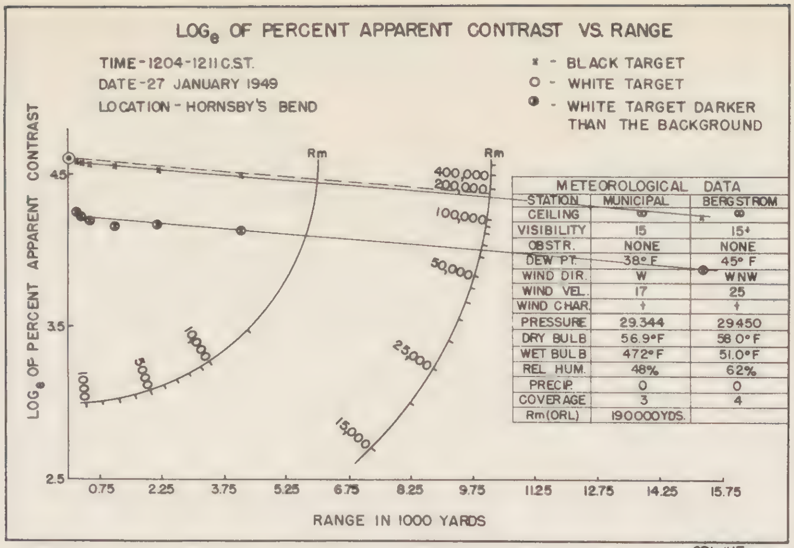
β = ATTENUATION COEFFICIENT
R = DISTANCE FROM PHOTOMETER TO TARGET
R_M = METEOROLOGICAL RANGE (DEFINED TO BE THAT RANGE AT WHICH A TARGET OF ZERO INHERENT BRIGHTNESS HAS AN APPARENT CONTRAST OF TWO PERCENT).

ORL/UT
19 FEBRUARY 1949
D-6008

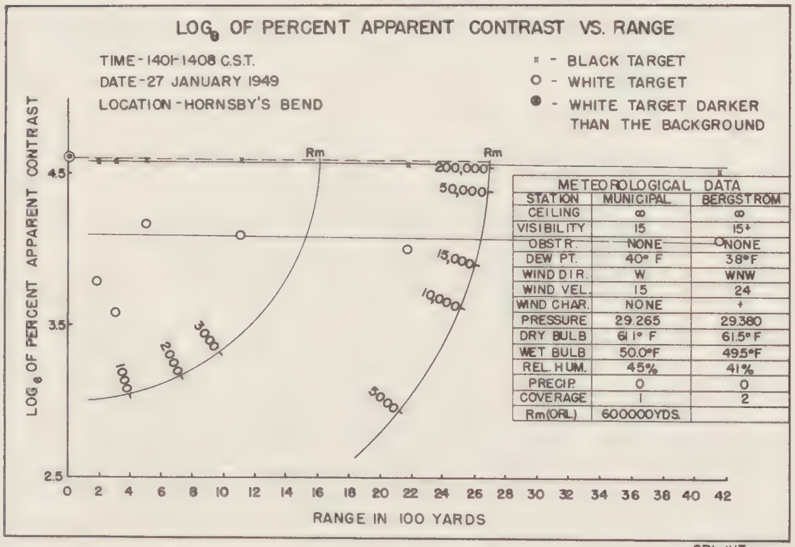


METEOROLOGICAL DATA		
STATION	MUNICIPAL	BERGSTROM
CEILING	∞	∞
VISIBILITY	15	15+
OBSTR.	NONE	NONE
DEW PT.	38° F	39° F
WIND DIR.	S	SW
WIND VEL.	15	16
WIND CHAR.	NONE	NONE
PRESSURE	29.310	29.430
DRY BULB	64.0°F	63.5°F
WET BULB	50.8°F	51.0°F
REL. HUM.	39%	41 %
PRECIP.	0	0
COVERAGE	2	2
Rm (ORL)	92000 YDS.	

ORL/UT
7 FEBRUARY 1949
D-6022



ORL/UT
27 JANUARY 1949
D-5907



ORL/UT
27 JANUARY 1949
D-5912

VARIATION OF TARGET ILLUMINATION AS A FUNCTION OF TIME

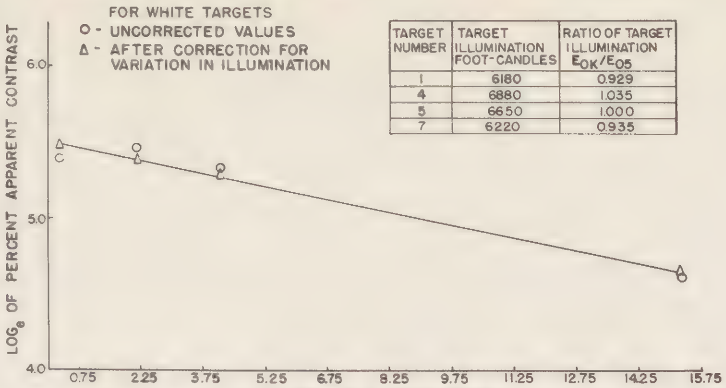
9 FEBRUARY 1949

TIME C.S.T. HR	MIN	SEC.	TARGET # 1	TARGET # 4	TARGET # 5	TARGET # 7
16	40	00	2520	2250	2300	4640
	41	00	2800	2140	2160	3790
	42	00	2190	2410	2600	2180
	43	00	3110	2710	2160	2270
	44	00	3360	2850	3720	2040
	45	00	5600	3400	3310	3500
	46	00	6750	6460	5000	4170
	47	00	6730	6110	6420	3220
	48	00	7310	6390	6140	3500
	49	00	7340	6870	6370	5210
	50	00	7620	6890	6900	6060
	51	00	5810	7170	7000	6200
	52	00	4890	4640	6600	6720
	53	00	6980	5190	4140	7670
	54	00	5730	6070	5400	7480
	55	00	6600	5840	5590	7670
	56	00	6420	6570	6280	4830
	57	00	5480	6300	5890	6060
	58	00	5350	4780	5000	5590
	59	00	4890	4870	4600	6630

ORL/UT
22 FEBRUARY 1949
D-6027

GRAPH SHOWING THE INFLUENCE OF TARGET ILLUMINATION ON MEASUREMENTS OF ATMOSPHERIC ATTENUATION OF BRIGHTNESS CONTRAST AT A TIME WHEN THE METEOROLOGICAL RANGE WAS FOUND TO BE 58000 YARDS

OBSERVATIONS MADE 1503 - 1508 C.S.T. 11 FEBRUARY 1949



TARGET NUMBER	TARGET ILLUMINATION FOOT-CANDLES	RATIO OF TARGET ILLUMINATION E_{OK}/E_{05}
1	6180	0.929
4	6880	1.035
5	6650	1.000
7	6220	0.935

ORL/UT
11 FEBRUARY 1949
D-6014

A COMPARISON OF THE RATIOS OF CALCULATED BRIGHTNESSES WITH THE RATIOS OF TARGET ILLUMINATIONS FOR THE WHITE TARGETS

TARGET NO. 1 DATE: 11 FEBRUARY 1949

TIME C.S.T.	RUN NO.	B_{R1}	$\beta \times 10^5$ FOR BLACK TARGETS	R_m	B_{01}	B_{01}/B_{05}	E_{01}/E_{05}
1447	1	296	7.67	51000	316	0.916	0.954
1456	2	309	6.92	55000	333	0.943	0.944
1503	3	315	6.50	58000	343	0.948	0.929
1512	4	330	6.33	58000	347	0.935	0.962
1518 ½	5	339	6.50	60000	362	0.940	0.951
1525 ½	6	346	6.58	57000	361	0.926	0.972

NOTES:

(1) THE RANGE OF TARGET NO. 5 IS 4153 YDS.
(2) THE RANGE OF TARGET NO. 1 IS 300 YDS.
(3) SYMBOLS:
  a. B_{R1} - MEASURED BRIGHTNESS OF WHITE TARGET AT 300 YDS. (MILLIVOLTS)
  b. β - MEASURED ATTENUATION COEFFICIENT (1/YDS.)
  c. R_m - MEASURED METEOROLOGICAL RANGE (YDS.)
  d. B_{01} - CALCULATED INHERENT BRIGHTNESS OF WHITE TARGET NO. 1 (MILLIVOLTS)
  e. B_{05} - CALCULATED INHERENT BRIGHTNESS OF STANDARD WHITE TARGET NO. 5 (MILLIVOLTS)
  f. E_{01} - MEASURED ILLUMINATION ON TARGET NO. 1 (F.C.)
  g. E_{05} - MEASURED ILLUMINATION ON STANDARD TARGET NO. 5 (F.C.)
  h. B_{01}/B_{05} - RATIO OF BRIGHTNESS
  i. E_{01}/E_{05} - RATIO OF ILLUMINATION

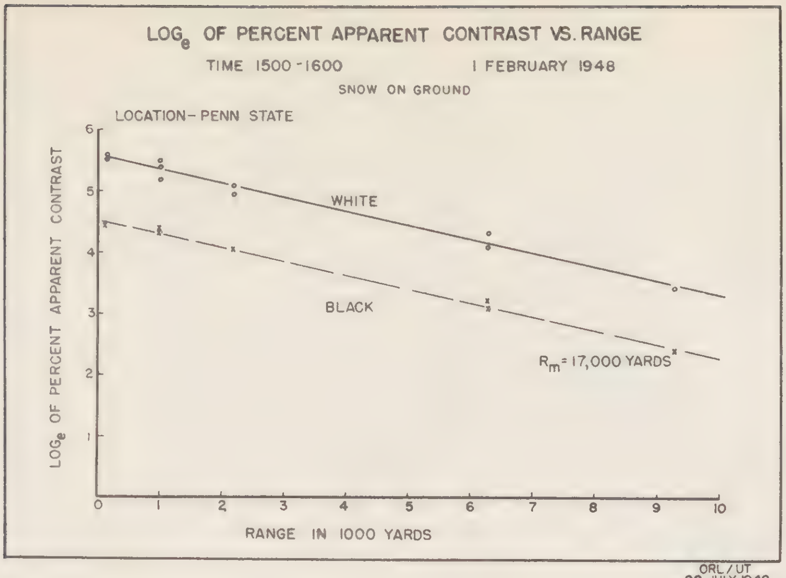
ORL/UT
22 FEBRUARY 1949
D-6023

VARIATION OF TARGET ILLUMINATION AS A FUNCTION OF TIME
11 FEBRUARY 1949

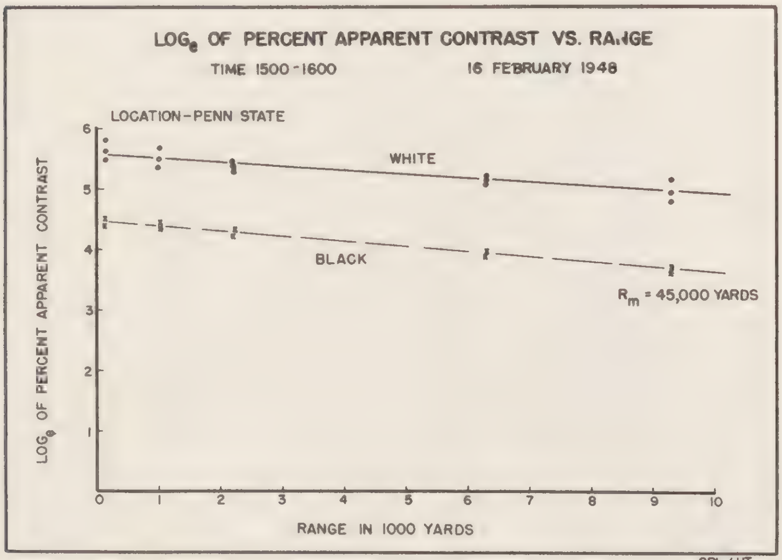
TIME C.S.T. HR. MIN SEC.	TARGET # 1	TARGET # 4	TARGET # 5	TARGET # 7
15 00 00	6230	6750	6375	5940
30	6200	6750	6400	5970
01 00	6230	6750	6425	5990
30	6200	6750	6425	6060
02 00	6200	6780	6450	6060
30	6180	6800	6450	6120
03 00	6180*	6830	6450	6160
30	6180	6850	6475	6160
04 00	6230	6850	6475	6160
30	6230	6850	6425	6170
05 00	6250	6880*	6525	6200
30	6340	6880	6550	6220
06 00	6360	6900	6600	6220
30	6390	6930	6650*	6220
07 00	6430	6950	6675	6220
30	6480	6950	6675	6220
08 00	6460	6980	6700	6220*
30	6480	6980	6725	6220
09 00	6480	6980	6750	6250
30	6520	6980	6750	6250

* VALUES USED IN CONNECTION WITH DATA SHOWN ON DRAWING NO. 6014

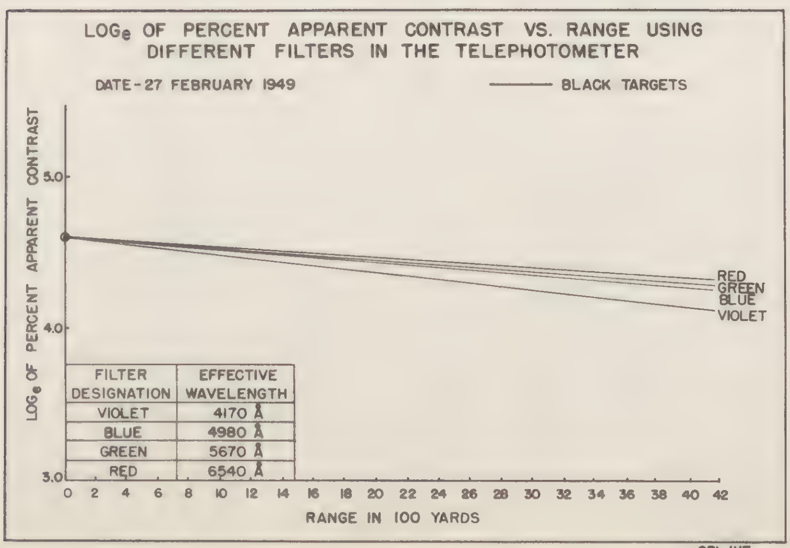
ORL/UT
22 FEBRUARY 1949
D-6028



ORL / UT
28 JULY 1948
D-5074



ORL / UT
28 JULY 1948
D-5081



ORL / UT
27 FEBRUARY 1949
D-6038

SAMPLE METEOROLOGICAL RANGE AND CEILING DATA

METEOR-OLOGICAL RANGE	CEILING - FT.		OBSERVATION DATE
	MUNICIPAL AIRPORT WEATHER STATION	BERGSTROM A.F. WEATHER STATION	
4600	M600	W900	12 JAN. 1949
6000	M 500	E 500	13 JAN. 1949
7000	W 300	W400	11 JAN. 1949
9000	W 300	W400	11 JAN. 1949
12000	W 400	W300	11 JAN. 1949
15000	W 200	W 200	10 JAN. 1949
25000	W 300	W 500	11 JAN. 1949
35000	W300	W 300	10 JAN. 1949
50000	E 25000	∞	6 JAN. 1949
60000	E 15000	E15000	5 JAN. 1949
70000	E 25000	E 23000	7 JAN. 1949
80000	M3100	E2500	8 JAN. 1949
90000	∞	∞	3 JAN. 1949
100000	∞	∞	18 JAN. 1949
140000	E18000	E14000	6 JAN. 1949
200000	∞	∞	18 JAN. 1949

WEATHER CODES

M - MEASURED CEILING HEIGHT B - CEILING MEASURED BY BALLOON
E - ESTIMATED CEILING HEIGHT W - INDEFINITE CEILING HEIGHT
∞ - UNLIMITED

ORL/UT
19 FEBRUARY 1949
D-5996

SAMPLE METEOROLOGICAL RANGE AND VISIBILITY DATA

METEOR-OLOGICAL RANGE	VISIBILITY - YDS.		OBSERVATION DATE
	MUNICIPAL AIRPORT WEATHER STATION	BERGSTROM A.F. WEATHER STATION	
4600	7,000	8,800	12 JAN. 1949
6000	5,300	7,000	13 JAN. 1949
7000	3,500	1,800	11 JAN. 1949
9000	3,500	1,800	11 JAN. 1949
12000	5,300	4,400	11 JAN. 1949
15000	5,300	8,800	10 JAN. 1949
25000	7,000	7,000	11 JAN. 1949
35000	8,800	8,800	10 JAN. 1949
50000	26,000	26,000	6 JAN. 1949
60000	21,000	26,000	5 JAN. 1949
70000	21,000	26,000	7 JAN. 1949
80000	21,000	26,000	8 JAN. 1949
90000	26,000+	26,000	3 JAN. 1949
100000	26,000+	26,000+	18 JAN. 1949
140000	26,000+	26,000+	6 JAN. 1949
200000	26,000+	26,000+	18 JAN. 1949

WEATHER CODE

26,000+ - IN EXCESS OF 26,000 YARDS

ORL/UT
19 FEBRUARY 1949
D-5997

SAMPLE METEOROLOGICAL RANGE AND OBSTRUCTION DATA

METEOR-OLOGICAL RANGE	OBSTRUCTIONS		OBSERVATION DATE
	MUNICIPAL AIRPORT WEATHER STATION	BERGSTROM A.F. WEATHER STATION	
4600	L-	L-	12 JAN. 1949
6000	R-L-	L-F	13 JAN. 1949
7000	L-F	L-F	11 JAN. 1949
9000	L-F	L-F	11 JAN. 1949
12000	R-L-F	R-L-F	11 JAN. 1949
15000	L-F	L-F	10 JAN. 1949
25000	L-	L-F	11 JAN. 1949
35000	L-F	L-F	10 JAN. 1949
50000	NONE	NONE	6 JAN. 1949
60000	NONE	NONE	5 JAN. 1949
70000	NONE	NONE	7 JAN. 1949
80000	NONE	NONE	8 JAN. 1949
90000	NONE	NONE	3 JAN. 1949
100000	NONE	NONE	18 JAN. 1949
140000	NONE	NONE	6 JAN. 1949
200000	NONE	NONE	18 JAN. 1949

WEATHER CODE

L- : LIGHT DRIZZLE
R- : LIGHT RAIN
F : MODERATE FOG

ORL/UT
19 FEBRUARY 1949
D-5998

SAMPLE METEOROLOGICAL RANGE AND DEW POINT DATA

METEOR-OLOGICAL RANGE	DEW POINT °F		OBSERVATION DATE
	MUNICIPAL AIRPORT WEATHER STATION	BERGSTROM A.F. WEATHER STATION	
4600	35	35	12 JAN. 1949
6000	41	40	13 JAN. 1949
7000	34	35	11 JAN. 1949
9000	34	35	11 JAN. 1949
12000	35	34	11 JAN. 1949
15000	38	38	10 JAN. 1949
25000	34	34	11 JAN. 1949
35000	38	37	10 JAN. 1949
50000	24	29	6 JAN. 1949
60000	17	23	5 JAN. 1949
70000	30	34	7 JAN. 1949
80000	59	57	8 JAN. 1949
90000	51	56	3 JAN. 1949
100000	33	32	18 JAN. 1949
140000	25	28	6 JAN. 1949
200000	32	31	18 JAN. 1949

ORL/UT
19 FEBRUARY 1949
D-5999

SAMPLE METEOROLOGICAL RANGE AND WIND DIRECTION DATA

METEOR-OLOGICAL RANGE	WIND DIRECTION		OBSERVATION DATE
	MUNICIPAL AIRPORT WEATHER STATION	BERGSTROM A.F. WEATHER STATION	
4600	NNW	NNE	12 JAN. 1949
6000	NE	NNE	13 JAN. 1949
7000	NNE	NNE	11 JAN. 1949
9000	NNE	NNE	11 JAN. 1949
12000	N	NNE	11 JAN. 1949
15000	N	NNE	10 JAN 1949
25000	N	NNE	11 JAN. 1949
35000	NNE	NNE	10 JAN. 1949
50000	NNW	WSW	6 JAN. 1949
60000	NNW	NNE	5 JAN. 1949
70000	SE	SSW	7 JAN. 1949
80000	SSW	SSW	8 JAN. 1949
90000	W	WSW	3 JAN. 1949
100000	W	NW	18 JAN. 1949
140000	S		6 JAN. 1949
200000	WNW	W	18 JAN. 1949

ORL/UT
19 FEBRUARY 1949
D-6000

SAMPLE METEOROLOGICAL RANGE VS. WIND VELOCITY

METEOR-OLOGICAL RANGE	WIND VELOCITY - MPH		OBSERVATION DATE
	MUNICIPAL AIRPORT WEATHER STATION	BERGSTROM A.F. WEATHER STATION	
4600	15	13	12 JAN. 1949
6000	6	7	13 JAN. 1949
7000	17	16	11 JAN. 1949
9000	17	16	11 JAN. 1949
12000	14	16	11 JAN 1949
15000	15	12	10 JAN. 1949
25000	14	16	11 JAN. 1949
35000	16	18	10 JAN 1949
50000	2	7	6 JAN. 1949
60000	8	9	5 JAN 1949
70000	5	9	7 JAN 1949
80000	22	20	8 JAN 1949
90000	9	12	3 JAN. 1949
100000	11	12	18 JAN. 1949
140000	9	CALM	6 JAN. 1949
200000	12	20	18 JAN. 1949

ORL/UT
19 FEBRUARY 1949
D-6001

SAMPLE METEOROLOGICAL RANGE VS. PRESSURE

METEOR-OLOGICAL RANGE	PRESSURE - in. Hg		OBSERVATION DATE
	MUNICIPAL AIRPORT WEATHER STATION	BERGSTROM A.F. WEATHER STATION	
4600	29.730	29 8 45	12 JAN 1949
6000	29 620	29.720	13 JAN. 1949
7000	29 690	29.810	11 JAN. 1949
9000	29 690	29 810	11 JAN 1949
12000	29.670	29.795	11 JAN 1949
15000	29.660	29.765	10 JAN. 1949
25000	29.775	29.860	11 JAN. 1949
35000	29 650	29.755	10 JAN. 1949
50000	29 675	29 780	6 JAN 1949
60000	29.560	29 660	5 JAN 1949
70000	29.6 00	29.710	7 JAN. 1949
80000	29 378	29.474	8 JAN. 1949
90000	28.880	28 970	3 JAN 1949
100000	29 390	29.500	18 JAN. 1949
140000	29.680	29.790	6 JAN. 1949
200000	29.380	29.500	18 JAN. 1949

ORL/UT
19 FEBRUARY 1949
D-6002

SAMPLE METEOROLOGICAL RANGE AND DRY BULB TEMPERATURE DATA

METEOR-OLOGICAL RANGE	DRY BULB TEMPERATURE °F		OBSERVATION DATE
	MUNICIPAL AIRPORT WEATHER STATION	BERGSTROM A.F. WEATHER STATION	
4600	37 2	37 2	12 JAN. 1949
6000	41.7	42 0	13 JAN. 1949
7000	35.0	33.1	11 JAN. 1949
9000	35.0	33.1	11 JAN. 1949
12000	36 0	36 0	11 JAN. 1949
15000	38 0	38.5	10 JAN. 1949
25000	35.1	35 9	11 JAN. 1949
35000	38.2	38.6	10 JAN. 1949
50000	58.9	58 0	6 JAN. 1949
60000	39 7	40.0	5 JAN 1949
70000	59 6	60 0	7 JAN 1949
80000	68 3	68.2	8 JAN 1949
90000	82.0	81.2	3 JAN. 1949
100000	48.6	50.0	18 JAN. 1949
140000	57.6	58.8	6 JAN. 1949
200000	46 0	47.0	18 JAN. 1949

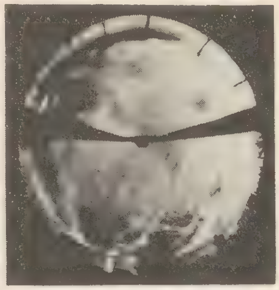
ORL/UT
19 FEBRUARY 1949
D-6003

SAMPLE METEOROLOGICAL RANGE VS. WET BULB TEMPERATURE

METEOR-OLOGICAL RANGE	WET BULB TEMPERATURE °F		OBSERVATION DATE
	MUNICIPAL AIRPORT WEATHER STATION	BERGSTROM A.F. WEATHER STATION	
4600	36.2	36.7	12 JAN. 1949
6000	41.3	41.0	13 JAN. 1949
7000	34.6	33 0	11 JAN. 1949
9000	34.6	33.0	11 JAN. 1949
12000	35.7	35.2	11 JAN. 1949
15000	38.0	38.0	10 JAN 1949
25000	34 4	35.0	11 JAN 1949
35000	37 8	38 0	10 JAN. 1949
50000	44.0	45.0	6 JAN 1949
60000	31.9	33.5	5 JAN. 1949
70000	45.9	47.5	7 JAN 1949
80000	62.2	61.2	8 JAN 1949
90000	62 9	65 0	3 JAN 1949
100000	41.8	42.0	18 JAN. 1949
140000	43 4	45 0	6 JAN. 1949
200000	40.0	40.0	18 JAN. 1949

ORL/UT
19 FEBRUARY 1949
D-6004

THE SKY COVERAGE RECORDER USED IN THE UNIVERSITY OF TEXAS ATMOSPHERIC OPTICS PROGRAM



PHOTOGRAPH OF SKY

ORL/UT
23 FEBRUARY 1949
P-5156

SAMPLE METEOROLOGICAL RANGE AND RELATIVE HUMIDITY DATA

METEOROLOGICAL RANGE	RELATIVE HUMIDITY %		OBSERVATION DATE
	MUNICIPAL AIRPORT WEATHER STATION	BERGSTROM A.F. WEATHER STATION	
4600	91	95	12 JAN. 1949
6000	97	92	13 JAN. 1949
7000	96	99	11 JAN. 1949
9000	96	99	11 JAN. 1949
12000	97	93	11 JAN. 1949
15000	100	96	10 JAN. 1949
25000	95	92	11 JAN 1949
35000	97	95	10 JAN. 1949
50000	26	33	6 JAN 1949
60000	39	49	5 JAN 1949
70000	32	37	7 JAN. 1949
80000	71	69	8 JAN. 1949
90000	34	41	3 JAN. 1949
100000	56	50	18 JAN 1949
140000	28	31	6 JAN 1949
200000	58	54	18 JAN. 1949

ORL/UT
19 FEBRUARY 1949
D-6005

SAMPLE METEOROLOGICAL RANGE AND COVERAGE DATA

METEOROLOGICAL RANGE	COVERAGE-TENTHS		OBSERVATION DATE
	MUNICIPAL AIRPORT WEATHER STATION	BERGSTROM A.F. WEATHER STATION	
4600	10	10	12 JAN. 1949
6000	10	10	13 JAN. 1949
7000	10	10	11 JAN. 1949
9000	10	10	11 JAN. 1949
12000	10	10	11 JAN. 1949
15000	10	10	10 JAN. 1949
25000	10	10	11 JAN. 1949
35000	10	10	10 JAN. 1949
50000	9	5	6 JAN. 1949
60000	9+	9	5 JAN. 1949
70000	10	9	7 JAN. 1949
80000	10	10	8 JAN. 1949
90000	0	0	3 JAN. 1949
100000	0	1-	18 JAN. 1949
140000	9+	9+	6 JAN. 1949
200000	0	1-	18 JAN. 1949

WEATHER CODE

9+ -MORE THAN NINE-TENTHS COVERAGE

1- -LESS THAN ONE-TENTH COVERAGE

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19 FEBRUARY 1949
D-6006

REPORT OF PROGRESS OF THE ROSCOMMON VISIBILITY TESTS
June 1947 - December 1948

H. Richard Backwell
University of Michigan

1. Introduction

The program of research initiated during World War II by the National Defense Research Committee intended to investigate the visibility of objects of military importance is familiar to most of you here. The program, and indeed the broad conception that the specification of the visual range of objects could be made with satisfactory precision, must be credited to Professor Arthur C. Hardy. The experimental investigations were undertaken by the L. C. Tiffany Foundation. It was intended that the Tiffany program include a comprehensive study of the two factors concerned in visibility: (1) scattering and absorption of light by the atmosphere, and (2) response to light by the human eye. The human visual response was studied under a wide range of conditions similar to those encountered in the field when the target is relatively stationary, and complex functional relations have been reported by the speaker, relating the light necessary for vision to such variables as target size, sky brightness, and target brightness. Preliminary studies of atmospheric attenuation of light, reported by Professor S. Q. Duntley, led to tentative acceptance of Koschmieder's law as an expression for the relation of attenuation and target distance from the observer. These two kinds of data were combined into the Tiffany visibility nomographs, from which visual range may be determined knowing the attenuation coefficient, B, of the atmosphere and the target size, target brightness, and sky brightness.

Use of the nomographic charts, by those of us familiar with their construction, has been restricted for three reasons. First, we did not consider there to be adequate assurance that Koschmieder's law could be assumed to hold for practical situations. Second, we had not proved that the number of visual detections in the field could be predicted from the number of detections made in the laboratory. Third, we had no assurance that existing instruments intended to measure the atmospheric attenuation coefficient, B, measured the quantity in the manner assumed by the visibility nomographs.

The applicability of Koschmieder's law in describing the reduction of target contrast with distance has been studied by Professor H. S. Coleman, first at Pennsylvania State College and more recently at the University of Texas. The Roscommon Visibility tests were designed to provide answers to the other two questions: (1) to what extent are laboratory visual detections useful in predicting detections in the field and (2) to what extent do available B-meters predict the reduction of target contrast in passage through long paths of intervening atmosphere.

We were hopful that our tests would prove laboratory measurements predictive of field visual detections, because we envisaged field studies of visual detection to be extremely difficult. We have learned that our original estimates of the difficulties of field tests of visual detection were extreme underestimates. We can now appreciate, at least in part, the difficulties encountered by Comdr. Dayton Brown, for example, in his tests of submarine detection.

Exploratory studies were made during the summer of 1947 which have been reported to this Subcommittee. The measurement of visual threshold, only, was

undertaken. Improved equipment and procedures were developed and more adequate visual threshold tests and tests of B-meters were conducted during the period from June 1 to December 1, 1948.

II. 1947 Tests

I believe it will be necessory to renew briefly the 1947 facilities and procedures, as well as the experimental data obtained, in order to make clear the purposes of the various changes introduced.

The first requirement for outdoor visibility tests is that stimulus objects of controlled size and brightness be introducable in the visual field above the horizon line. To achieve this objective, one must either work over open water or else with targets erected on hill tops against the sky. It was decided that our field tests would be run over land in order to simplify various operational problems. It was required, therefore, that means be provided for suspending target objects above the tree line on various hilltops. Forest fire lookout towers appeared the logical means for such target presentation. After some inquiry, a series of fire lookout towers located near Roscommon, Michigan, and belonging to the State Department of Conservation, was located. The towers were made available to the project through the generous cooperation of the Conservation Officers.

A central fire tower was selected as an observation post. Located around this tower, at varying distances, were thirteen fire towers, each visible against the sky. The ground between towers was nearly uniformly covered with forest. Before actually commencing the project, it was planned that some six or seven of these towers be used for observations with naked eye and with binoculars, by night and by day. Construction problems reduced the number of target towers used to three. It was planned that large billboard type targets with continuously variable contrast be prepared and mounted on the several lookout towers. In addition plans were made to utilize search-lights as targets for the night observations. A staff of seven young men was assembled for the Roscommon mission.

Physical difficulties soon became apparent. The line-of-sight distances between the observation post and the target towers were 6, 10, and 20 miles. Translated into distance along the dusty country roads, these grew into hundreds of miles of driving per day. Jeeps and pickup trucks were made available to the project by the Navy. The heights of lookout towers were found to be a serious obstacle. All equipment had to be mounted at least 60 feet above the ground level. Mounting platforms were built, and targets mounted as is shown in Figure 1. The target is a 6 x 12 foot billboard, capable of continuous adjustment in brightness by continuous adjustment of the percentage of incident illumination reflected in the direction of the observer.

The target consisted of a black billboard in front of which were mounted white vanes which could be rotated from vertical to horizontal. The position of the vanes was controlled by a lever arm mounted on the tower platform. Since the entire target was below the resolution limit of the eye as viewed from the observation post, variation in the amount of white vane present varied the integrated reflectance of the target. As the target reflectance was varied, the target's brightness varied from greater than, to less than the sky brightness, provided the incident illumination was sufficiently great. A given target could be used only either morning or afternoon since direct illumination from the sun was necessary to its successful operation. A searchlight was also mounted at this tower installation, 6 airline miles from the observation post.

The first task of the project crew was to construct three such platforms and target assemblies. In addition, the observation post was fitted with a stable platform on which the observers' station and the physical recording equipment were mounted.

Communication was maintained between the towers with Army radio equipment. The radio sets were operated from storage batteries. Since no power was available at the lookout towers, motor generator sets were obtained from the Navy to maintain the storage batteries.

The first problem encountered after installations were complete arose from the desire to present a target in the midst of a uniform portion of sky. It was desired that the target appear to be suspended in space without visible support so that the tests would measure visual detection rather than a change in the appearance of an always visible object. The billboard type targets were extremely small with respect to the total height of the towers. Calculations from laboratory data had indicated, however, that the compactness of the target would render it more visible than the entire spider-legged tower structure. This prediction was found to be universally true. However, the tower structures were often quite visible under many of the atmospheric conditions encountered. It was therefore necessary somehow to obscure the tower structure without rendering the target less visible. It was finally decided that the tower structure could best be obscured by painting it so that during a substantial portion of the day its brightness would be a good match with the horizon sky. The simplest means of obtaining a delicately adjusted reflectance was to paint white stripes around the tower structure. These stripes, integrated with the gray patches left unpainted, could be made to produce just the right reflectance for match with the sky by varying their width.

In Figure 2 we see two members of the project crew applying white paint to a tower structure. At 100 feet above the ground, this becomes rather a difficult performance. It was found that there was usually a one to two hour period during which each of the towers was invisible after careful painting. The most difficult part of the tower to obscure was the tower cab, but in each case the cab was sufficiently distant from the target so that small errors in masking were not expected to affect visual detections.

The most difficult problem encountered in the project was the successful recording of the small amounts of light necessary for threshold detection by the human eye. Because of the large amount of atmospheric boil present over the long distances used in this experiment, it was obligatory that recording of the stimulus value be accomplished in extremely brief and frequent intervals of time. Motion picture photography was adopted, utilizing a 30 power telescope and a standard Navy 16mm. gun camera. It was possible to obtain reasonably adequate photographic records of the targets, with this equipment. Because of the high magnification, it was necessary to provide a rigid support for the photographic equipment, a height finder tripod being utilized for the purpose. Considerable difficulty was encountered in providing a calibration for each frame of the photographic record. The standard technique of inserting a "gray scale" in the field of the camera was not feasible since it would involve construction of a number of special towers 50 to 60 feet in height. Instead, a special optical system was used which produced a series of calibration brightness upon each frame. From these known brightnesses, the characteristic curve of the photographic material for each frame could be plotted and target brightness determined. The tripod, telescope, camera, and calibration system are shown in Figure 3.

The psychophysical procedure used in the experiments was chosen for complete comparability with the laboratory procedure used in the Vision Research Laboratory. With this method, each target presentation includes four time intervals, in only one of which a target appears. It is the task of the observer to report in which interval the target appears, the observer being forced to guess the most likely time interval for each target presentation even though he may not feel certain of his response. The duration of each of the time intervals was standardized by the towerman who synchronized his movements to beats from a metronome mounted in each of the lookout towers. A predetermined sequence was followed in presenting targets to the observer. With the billboard type targets, the vanes were first set at a position which would render the target invisible against the horizon sky. The tower man operating the vanes was in radio communication with the experiment monitor in the observation post. The monitor in the observation post used 10-power binoculars in setting the invisibility point so that an extremely precise setting was possible. The vanes of the venetian-blind target were then set to provide a bright stimulus of sufficient magnitude to be detected approximately 50% better than chance. This setting of the vanes was also made upon instructions from the monitor in the observation post. Having set the two positions of the vanes for invisible and target values, the tower man began his series of presentations, calling the designation numbers of the presentations and the presentation intervals over the radio set. In Figure 4 we see the apparatus used in positioning the target vanes. There was a lever arm connected with the vanes. Two limiting blocks were placed corresponding to the invisibility point and to the target point respectively. The tower man had merely to alternate the lever arm between the two alternating positions set by the blocks in time to metronome beats, three invisible presentations being coupled with each target presentation. A series of 20 presentations of a given stimulus value was given. During the entire sequence of trials, the monitor in the observation post watched the target presentation through 10-power binoculars. He recorded the observers' resonses as well as the correct responses and was therefore able to evaluate the data obtained.

In Figure 5, we have an overall view of the observation post in action. At the upper left we see the monitor seated at the radio set with binoculars in position. At the lower right-hand corner we see the telescope and tripod mount. Toward the upper center section, we can detect the observer in the process of observing. The experimental procedure followed this order: The target vanes were set for invisibility and the monitor estimated the value of the stimulus which would be detected approximately 50% better than chance. A series of twenty observations was made, utilizing the same stimulus. A photographic record of masking and target brightness values was then obtained. The observer responses were scored and appropriate changes were made in the stimulus so that percentages both greater and less than 50% were obtained with successive values of the stimulus. It was never possible to obtain more than 80 observations in a given session because of the change in conditions related to the changing position of the sun. For this reason, the collection of data was a slow and uncertain affair. The presence of broken clouds made observation impossible because of radical changes from time to time in the tower masking. Since the daytime experiments depended upon the sun's illumination for lighting the target vanes, experiments could not be conducted under fog or hazy conditions.

Installing a standard Navy signalling searchlight in one of the towers was a comparatively simple matter. The face of the searchlight was masked down to 4 inches square so that reduction of the searchlight intensity could be produced by standard laboratory gelatin filters. The vanes of the signalling searchlight

were then used to shut off the stimulus in the same type of temporal sequence used with billboard targets. Searchlight experiments were conducted at night when the tower was completely invisible.

To achieve the objective of the experiments, it was necessary that the observers determine their threshold in the laboratory and in the field under similar conditions. For this purpose, a special room was prepared in the Vision Research Laboratory and the threshold intensity of point sources was determined for day and night brightness levels with the naked eye and with Navy 5 x 50 binoculars. These laboratory conditions corresponded to the day and night tests in the field since all targets used were below the resolving limit of the eye.

In order to calibrate contrast reduction in the optical system of the photographic recorder, known point source intensities were photographed in the laboratory with the entire optical assembly later used in the field. Since photographic records were made near threshold intensity both in the laboratory and in the field, the photographic technique was considered to be a null photometer. It was possible to obtain absolute intensity values in the laboratory by visual photometry so that the absolute intensities required for threshold in the field could be computed.

All equipment was put in working condition finally with but one week of experimental time remaining. During this brief time, a few systematic visual observations were made. Observations of billboard targets by day were made with the naked eye be each of two observers and with 5 x 50 binoculars by one observer. Observations of searchlights at night were made with the naked eye and with binoculars, each by one observer.

The data may best be evaluated by plotting them together with the corresponding observational data obtained in the laboratory visual detection sessions. Figure 6 shows data for naked eye detections by day. The dots represent laboratory data, fitted on the average by the solid curve. The crosses represent observations made in the field. There is scatter in the laboratory points which can be shown to arise from random sampling error. The crosses represent a significant trend in the direction of greater visual sensitivity in the field than in the laboratory. Figure 7 presents corresponding data for the second observer. Here also we find evidence for significantly greater sensitivity in the field than in the laboratory. The differences are approximately 40%.

In Figure 8, we have plotted the data for a 5-power binocular run by day. Our field observations are scattered at greater and smaller values than the laboratory values. Naked eye data obtained at night are plotted in Figure 9, and we have evidence for significantly less sensitivity in the field than in the laboratory tests. In Figure 10, the night-time data with binoculars demonstrates significantly greater sensitivity in the field than in the laboratory.

The data represents only 1664 observations made in the laboratory and 340 observations made in the field which is a relatively small number in terms of expected data variability due to random errors. There is no apparent trend in the data, some situations representing greater, some less sensitivity in the field than in the laboratory. We felt justified in concluding that, under the conditions tested, field and laboratory detection values were equivalent, within ± 35%. The generality of the equivalence even within these limits could not be assumed, however, since all measurements were made during a meteorological condition resulting in unusually clear air.

The most surprising result from the field experience concerned the degree of optical distortion of the targets produced by atmospheric "shimmer" or "boil." For the billboard targets, this resulted in unsteady apparent edges and occasional squirming of the target. In the case of the searchlights, the "shimmer" effect resulted in large fluctuations in apparent intensity with time, leading to a "twinkling" effect. This occurred both at night and by day. In analyzing the data, the assumption was made that the eye responded to the average illumination striking it, independently of the spatial and temporal distortions observed. The assumption of equivalence between a fluctuating and a steady stimulus cannot be considered generally correct, because of well established laboratory findings to the contrary. The fact that we encountered large-scale shimmer effects in the summer of 1947 led us to expect these effects to be a source of possible important differences between laboratory and field detections. However, we gained the distinct impression that, under our conditions of test, differences in general appearance of objects and differences in observer comfort in the field and in the laboratory would produce only negligible differences in detections.

We believed it necessary to conduct more extensive tests during the summer of 1948. First of all, we hoped to extend our measurements to a variety of meteorological conditions so that our conclusions would possess greater generality. We hoped to isolate differences in detections between the laboratory and the field due to shimmer from those due to other factors by utilizing one target possessing large-scale shimmer effects and a second possessing smaller shimmer effects. In order to extend measurements to clearer days than those encountered during 1947, the addition of a target at a farther distance than 20 miles was necessary. An appropriate fire-tower at a distance of 30 miles was selected and permission obtained to use it during the 1948 tests. In order to extend measurements of thresholds to hazy weather conditions, it was decided that some sort of orientation would have to be supplied to the observers so that they would direct their eyes directly at the target even though natural landmarks were obliterated. If no orientation were provided under hazy conditions, we felt confident that a large decrement in successful detections would occur. Since orientation is not a factor in the usual field situation in which the observer must expect the target at any point in a relatively large area of the visual field, we wished to exclude this factor from our experiments. Our desire to make observations on hazy days also indicated the need for self-luminous targets of high brightness.

The procedure used in 1947 for the night runs involved reduction of searchlight intensity over 4 or 5 log units by means of gelatine filters placed before the searchlight aperture. Members of the Subcommittee expressed concern over the validity of photometric measurements based on the assumption of equivalent reduction by the filter in the laboratory and in the field. The filters are known to possess considerable scattering. The presence of significant secondary atmospheric scattering would render the reduction factors determined in the absence of atmosphere invalid. For this reason, it was recommended that reduction in target brightness during night runs be performed in a manner which would insure the absence of any change in the optical properties of the light source.

It was agreed that motion picture recording equipment utilized in 1947 was not entirely adequate. The images of 6 foot targets at distances up to 20 miles barely exceeded the grain size of the photographic emulsion. With extension of distance used to 30 miles, the difficulty becomes almost prohibitive. It was decided that at least 5 times as great magnification of the image was needed.

16mm. film was not wholly satisfactory because of the proximity of test densities to the edge of the film. For this reason, it was agreed that 35mm. film would be adopted. The technique adopted for comparative photometry of laboratory and field stimulus intensities had the advantage that it permitted us to eliminate the necessity for evaluating contrast-reducing stray light in the optical system. The technique had the distinct disadvantage that we then had no idea to what extent our comparative laboratory and field measurements did indeed represent equivalent conditions with respect to the photographic recording system. We thus had no basis for separating satisfactory from unsatisfactory data. We planned, therefore, to develop exact methods for calibrating stray light in our photographic systems. Exact photographic evaluation, rather than presumed null photographic evaluation would permit us to select the satisfactory from the unsatisfactory data. As we shall see, this becomes an important point in the sensitometric evaluation of our data.

In view of the generally encouraging agreement between the few data obtained in the field and in the laboratory, during the 1947 tests, it appeared desirable to expand the tests to include tests of various B-meters in the 1948 tests. Thus, the 1948 tests were expected to yield not only an adequate estimate of the degree of equivalence of laboratory and field data but also an estimate of the degree to which available instruments could be used in visual range predictions in the field. A test of B-meters necessitates some measure of the actual reduction in target contrast by the atmosphere against which the B-meter predictions may be evaluated. Photographic determinations of target contrast at "zero distance" and at the observation post would yield the desired datum. Target contrast determinations at the observation post were necessary for determination of visual detection thresholds. We needed to add, therefore, only a simultaneous determination of target contrast close aboard.

III. 1948 Tests

In order to provide for the suggested changes outlined above, the winter and spring of 1947-48 were spent in extensive construction of equipment.

Orientation lights were constructed for each of the four target towers by modifying 60" searchlight reflectors. Each reflector was mounted rigidly in a steel frame. (Figure 11) In front of the reflector, an aluminum box was mounted, housing a 1,000 watt projection lamp. (Figure 12) A shutter was mounted between the lamp and the reflector, thus providing a means of rapid presentation and extinction of the orientation light. The shutter was controlled by a pair of rotary solenoids, activated by remote control through a synchronous-motor timing device. The timer turned the orientation light on for four brief periods and one extended period during each target presentation. Each brief period marked the beginning of a time interval during which the stimulus might be presented. The long presentation occupied the "rest period" between presentations, and served to keep the observer oriented and ready for the next sequence of four demarcated time intervals. Experiments in the laboratory established a duration for the brief flashes which permitted adequate orientation regardless of the general identification characteristics of the visual surround. Threshold determinations in the laboratory utilized a timer exactly like those installed on the four towers so that conditions of orientation were equivalent in the laboratory and in the field. The orientation lights were entirely satisfactory under all conditions, rendering the observer's orientation constant.

When the target was presented, the orientation light was turned off. In order that the "off" orientation light might not provide a bad match with the sky brightness, the shutter which excluded the projector beam from striking the reflector was not opaque but perforated. A series of shutter paddles with different degrees of perforation were available so that a satisfactory masking brightness could be obtained when the orientation light was "off". This arrangement proved thoroughly satisfactory.

An electric buzzer was activated by the timing device each time the orientation light was turned on. The towerman guided his positioning of the target lever by the buzzer signals. Following a prescribed schedule, he could present the stimulus value of the target during the proper time interval and present the invisible value of the target during the other three intervals.

The use of a mechanical timer to replace the hand-timing, based on beats of a metronome, employed in the 1947 tests was indicated by the suggestion made by a member of the Subcommittee that he could detect the time interval during which the stimulus presentation was made by the tone of voice used by the towerman in announcing the number of the time interval. With the mechanical timers, presentation of the stimulus was still controlled by the towerman, but such an extraneous cue was no longer possible.

The basic target for each tower was a special multi-purpose target. (Figure 13) The target consisted first of a white light box, filled with 200 6-foot bar flourescent lamps, with a white screen mounted at the front. With all lamps on, the brightness of the screen due to the lamps alone exceeded 2,500 footlamberts. Internal louvres were available at a considerable distance behind the white screen which varied the brightness due to the lamps from near zero to 2,500 footlamberts. In addition, a pair of removable black screens were available

behind the white screen which could be lowered into place by a window-shade arrangement. These screens, together with the internal louvres, provided for continuous adjustment of the brightness of the white screen from maximum brightness to 10^{-2} footlamberts without change in the emission charcteristics. A plexiglass sheet was mounted immediately in front of the white screen, thus sealing the unit against moisture and dust.

Since the white screen was exposed to illumination from sun and sky in the daytime, the brightness of the screen was greater than 2,500 footlamberts. Under favorable conditions, total brightness reached 9,000 footlamberts, which resulted in close aboard contrasts as great as 7-8.

Under such conditions, the general illumination provides a higher brightness by reflection than the brightness of the screen produced by the light box. In order to avoid use of the light box under these circumstances, a reflection-target feature was included in the target. A set of small vanes, similar in design to those used during the 1947 tests, was provided which could be positioned in front of the light box screen or removed to one side. When removed to one side, the reflector vanes were always adjusted to match the sky.

The vanes were white on one side and black on the other. Various vanes could be rotated with respect to each other so that a black and white striped target could be presented. After rotation, all vanes were engaged in a common drive mechanism so that they could be rotated together. This feature was included so that a wider range of reflectances could be obtained, resulting in more sensitive adjustment of the target contrast. Whenever the reflection vanes were utilized, one of the black screens was lowered behind them, and the white screen was raised. Figure 14 shows the reflection vanes positioned in front of the light box. Figure 15 shows one of the four tower installations. Note the two platforms, the orientation light mounted on the upper one, the multi-purpose target on the lower one. The platforms were separated as far as possible so that any failure of the orientation light to match the sky brightness when in the "off" position would have minimum effect upon detection of the target. In this tower, the target is arranged with the white screen lowered in front of the light box and with the reflection vanes all on white, removed to the right. The light box was not turned on when this photograph was made.

In Figure 16, we see the white screen on the left and mixed black and white reflection vanes on the right. The reflection vanes are not fully nertical so that sky may be seen through them. In Figure 17, we see the same installation with one of the black screens lowered in front of the light box. The apparent lack of blackness of the left side of the target is largely an error in photographic reproduction, since sensitometric evaluation has indicated that such an arrangement resulted in dark target contrasts always greater than 0.90.

Note the boom suspended in front of the target. A 35 mm. still camera was mounted on a track machined on the boom. The camera was cranked out the length of the boom. At the end of the boom, a spring-stop arrangement operated the shutter of the camera. The camera photographed the mulit-purpose target, the horizon sky, and a series of calibration brightnesses obtained by mounting opal light boxes on the tower platform. The brightness of a given arrangement of the multi-purpose target and the horizon sky could thus be measured from a distance of 20 feet. A simultaneous measurement could be made with the telescopic camera located at the obsevation post. From these measurements, the reduction in target contrast could be computed and a value of B, the atmospheric attenuation coefficient, computed assuming Koschmieder's law.

Power supply for the light boxes was a serious problem. Each of the four boxes required nearly 15,000 watts to run at full power. Four motor generator sets such as the one shown in Figure 18 were installed at the base of each tower. The towers gave a good simulation of a B-29 in flight when all generator sets were operating.

Electrical ballast boxes for the flourescent lamps were mounted on the tower platform, and represented a ton of dead weight for each tower. Each light box assembly weighed nearly a ton in addition, so that installation represented delicate operation.

In addition to the multi-purpose target, each tower was equipped with a standard Navy 12" signaling searchlight for use in visual detection runs in the daytime. Small adjustments of intensity were made by changes in voltage. For night visual runs, the multi-purpose targets were supplemented by modified 12" searchlights. A projection system formed a filament image on a diffusing surface located at the point usually occupied by the lamp filament. Gelatine filters introduced in the projection system reduced the brightness of the filament image, thereby reducing the intensity of output of the searchlight without altering the optical characteristics.

These targets provided a satisfactory solution to the various requirements set by the program. Both the light-box and the standard searchlight provided high intensity targets for use on overcast days. Because of difference in size and collimation, the light-box and standard searchlight provided targets for daytime use which differed widely in shimmer effects. The light-boxes were never observed to demonstrate significant shimmer effects. The searchlight exhibited a high degree of twinkle, undergoing variations in intensity of more than four to one in short periods of time. Comparison between detection thresholds for these targets could therefore be expected to permit separation of shimmer from other outdoor effects.

For night-time observations, both the modified searchlight and the light box represent targets for which satisfactory physical reduction over 4 or 5 log units was possible. Here too, large differences in shimmer effect were noted, the light-box showing no effect whatsoever while the searchlight showed large-scale twinkle. Here again we could expect to be able to separate shimmer from other outdoor effects.

The light-box targets permit contrast reduction measurements to be made both day and night so that B-meter could be evaluated under all practical conditions.

A very satisfactory photographic recording system was assembled. Special appreciation should be expressed to Dr. Duncan MacDonald, Director of the Optical Research Laboratories, Boston University, who made the telescopic system available on loan. A 50" collimator, of 9 inch diameter, was used with a microscope objective to form an image directly on the film in an Air Forces 35mm. motion picture camera. The camera has a viewer arranged so that a satisfactory image may be had during the period of photographing the target. A series of calibration brightnesses was imaged on each frame by means of a separate optical system. The camera and telescope assembly is shown mounted on the height-finder tripod in Figure 19.

Contrast and flux reduction were measured for the recording system as a whole. There was perfect flux rendition for all image sizes used and a contrast

rendition loss of only 10% for the smallest target used. These values were corroborated by two separate measurements series.

Three B-meters were tested in daytime runs. The first of these was the British-made Disappearance Range Gauge. The Disappearance Range Gauge was fitted over one half of a 10 x 70 binocular. The device operates by introducing artificial contrast rendition until a large black object at a known distant just disappears from the field of the binocular. Distant mountains were used for Disappearance Range Gauge measurements. From known distances to the mountains, by assuming Koschmieder's law, and a visual detection threshold of 0.02 for large objects, values of B may be computed.

The second instrument tested has been designated the Black Box photometer. Professor Duntley suggested the construction and use of this photometer. In principle, the brightness of the horizon sky and of a black box at a known distance are compared. Professor Duntley has shown that the ratio of these brightnesses gives a direct measure of B. The difficulty with this principle is that the black box must be nearly perfectly black if the air path distance from photometer to black box is to be made a reasonable length. For clear days and a distance of 10 feet, the reflection factor for the black box must not exceed 4×10^{-7}.

Mr. Pritchard of my laboratory developed a black box with a reflection factor equal to 1×10^{-7} by mounting two plates of specular black glass at an angle of 12° to each other at the end of a long black box filled with baffles. No light ray could emerge without having undergone multiple reflections and in this way, the exceedingly small reflection factor demanded was achieved. The photometer used was a Macbeth Illuminometer with objective lens attached and with a special baffling system arranged to minimize stray light within the photometer. The use of this instrument involved measuring the brightness of the black box mounted in a fixed location, then realigning the Macbeth to measure the horizon sky adjacent. These measurements had to be accomplished 40 feet above ground level in such a manner so as to eliminate the possibility of tower shadows across the air path. The resulting arrangement is indicated in Figure 20. The young lady has squirmed her way onto a two foot ledge protruding over empty space. She is making photometric settings of the brightness of the black box from this rather unorthodox posture. It should be emphasized that the Black Box photometer is clearly a crude instrument as tested, and that it was our intention to test merely the validity of the principle behind such a meter. Like the other B-meters, the Black Box photometer assumes Koschmieder's law.

The British instrument, the "Loofah" was also tested. This device consists of a large chest into which samples of air are drawn. The sample air column is illuminated from one angle and the relative brightness of the source and the illuminated air comumn is determined. Assuming a calibrated relationship between these quantities and B, it is possible to determine B in the field with this device. We may see the nature of the device in Figure 21. Unlike the other two instruments, the Loofah may be used at night as well as in the daytime.

The experimental procedure followed may be summarized as follows: The entire crew manned the towers two of three work periods each day: morning, afternoon or evening. Morning runs involved manning both the 6 and 10 mile towers. As soon as radio contact was made, the satisfactoriness of tower masking was determined by adjusting the multi-purpose target brightness to a match with the sky.

If tower masking was found to be unsatisfactory, what were called "B runs" were made. These runs usually involved measurement of contrast reduction for the multi-purpose target. Measurements were planned for each the 6 and 10 mile targets so that values of contrast reduction would be obtained over two air paths. Nearly simultaneously, the three B-meters were read.

When tower masking conditions became satisfactory, a series of visual target presentations was made following the procedure outlined above. The number of correct detections was recorded and a series of photographs taken of the target under the exact conditions utilized for the observations. On very few days was it possible to obtain threshold data either because of consistently unsatisfactory tower masking, unstable illumination conditions, or because of some form of equipment failure, the varieties being almost unlimited. B runs were somewhat more frequent because unsatisfactory masking was of no consequence. Close aboard photographs often failed, however, due no doubt principally to the rather precarious conditions under which the towerman was forced to work.

Afternoon runs differed from morning runs only in that the two towers facing west were used, in order to utilize direct sun's illumination. To the other difficulties was added the fact that relatively small changes in B produced large effects upon the usefulness of the long afternoon ranges, 20 and 30 miles.

Night runs involved an entirely new series of difficulties. Tower masking was of course no problem. The difficulties arose from problems of determing the correct exposures for photographs both close aboard and at the observation post. Threshold intensities can, of course, not be photographed directly at night. It is necessary to photograph the maximum intensity of a light source at the eye, and measure both this value and the setting used for threshold close aboard. Measurement of the maximum value at the observation post and of the threshold value close aboard often involved long time exposures and trouble was encountered with camera vibrations, particularly with the boom-mounted cameras. Even though an attempt was made to conduct a complete series of different exposures each time, often no satisfactory exposure was obtained. The basic difficulty, no doubt, stems from the rather unsatisfactory nature of the task of working in a shaky tower 60 feet above the ground at night. Also, as we shall note, the necessary conditions for adequate sensitometry are much more difficult to attain at night than in the daytime.

Although B runs were usually made with the multi-purpose target set for a value brighter than the sky, on numerous occasions B runs were made with the target set for darker than the sky. There is no convincing evidence that the equivalence of contrast reduction for bright and dark targets may not be assumed. On several occasions, atmospheric attenuation values were determined with the 12" searchlights. Close aboard photographs of these targets were not possible because of the criticalness of the angle from which the searchlights are viewed. Close aboard values were obtained from calibrations of unattenuated candlepower made before and after the series of tests by illumination measurements.

Because of the possibility of optical distortion of the image of the targets by passage through the atmosphere, the basic sensitometric measurement of the film density produced by a target was a flux measurement. We wished to determine the increment of illumination at the observer's eye produced by the target. This quantity may be related to a simple measurement of the difference in flux transmitted by a section of film corresponding to sky and a section of film

corresponding to sky and target, in unknown proportions, provided the size of the flux aperture is known in terms of the camera magnification. The only error introduced results because a densitometer adds flux whereas the relation between illumination striking the film and flux transmitted by the film is logarithmic. This "error" in evaluation may be compensated exactly if the relative areas and brightnesses of the sky and target falling within the flux aperture are known. An adequate compensation may be made if sky and target brightness are nearly alike even without information concerning the relative areas of sky and target. This situation occurs in daytime photography. In night photography, the sky and target brightness are extremely different. Under these circumstances, adequate compensation can be made only if the exact shape of the photographic characteristic curve is known over wide ranges, or if the relative areas of target and sky in the flux aperture are known with good precision. The first possibility is almost impossible to realize in any event and the second is impossible if any camera vibration occurs during a time exposure.

These considerations make it possible for definite standards to be set for acceptance or rejection of the data from a given experimental run. It was frequently necessary to discard daytime data on sensitometric grounds and it was almost always necessary to discard night time data. Data which meet the objective standards can, however, be accepted with confidence.

The visual threshold data obtained have been plotted in the same manner as the data presented previously. In Figure 22 we have the data for observer A.O. for daytime naked eye runs with the multi-purpose target.

The difference between laboratory and field data is not significant. Similar data are presented for observer J.O. in Figure 23. The field data exhibit somewhat more scatter than the laboratory data, but there is no better fit to the data than the curve drawn in to fit the laboratory data. In Figure 24 we have plotted similar values for this observer utilizing the 12" Navy searchlight. As we have noted above, this target exhibited considerable shimmer. The values obtained are not, however, significantly different from the values obtained with the multi-purpose target which failed to exhibit shimmer. Apparently under the conditions tested, the average value for the shimmering target defines visual performance. These data may be fit slightly better by adjusting this curve 10% in the minus direction, but the difference is not significant.

We have here convincing evidence that naked eye thresholds by day are equivalent in the laboratory and the field. Our physical measuring technique is completely satisfactory for the data. The experimental conditions tested represent variations in meteorological conditions over a satisfactorily large range.

The data obtained with 7 power binoculars by day do not meet the criteria for adequate sensitometric data. They are presented to give an estimate of variability introduced by inadequate measurement technique. Presented in Figure 25, we note considerable scatter but no systematic deviation from the average laboratory values. The data are not convincing except in a crude manner.

The only satisfactory night visual data analyzed to date are presented in Figure 26. Again we see no evidence of a significant difference between laboratory and field.

We have now obtained visual threshold measurements for naked eye, for 5 x 50 and 7 x 50 binoculars each by day and at night. In all, a total of four observers have been used. The total laboratory calibration data number 12,240; the total field data numbers less than 2,000. Although the data are quite meager from the point of view of a normal laboratory experiment, there would appear to be ample reason to accept the practical absence of other than chance factors existing between laboratory visual detections and field detections made under carefully controlled conditions. Apparently a tolerance of ± 25% would be cautious, in terms of data obtained with the more careful physical measurement techniques. We believe we may now consider the basic validation of the laboratory method of determining detection thresholds for use in detection predictions in the field satisfactorily concluded.

This statement does not imply that laboratory thresholds obtained under conditions of regular stimulus presentation apply directly to field situations where targets occur sporadically and unexpectedly. It implies merely, that investigation of the effect of unexpected or sporadic presentation can be conducted in the laboratory with good prospects of the values obtained being applicable to field use. In effect, this study provides evidence for our belief that we are aware of the pertinent variables in visual detection and that we normally evaluate them in the laboratory. We may go one step further and assume that laboratory threshold values probably represent the upper limit of visual ranges to be expected in the field.

It is interesting to average the laboratory thresholds for the four observers used in the field tests and compare the values obtained with the average thresholds determined at Tiffany which are built into the visibility nomographs. The high brightness value differs by 7%, the low brightness value by 25%.

Now let us examine the performance of each of the B-meters in terms of B computed from the photographic measurements of contrast reduction. Each B-meter reading usually had several simultaneous photographic B determinations, the number sometimes equalling 10 or 12. In each case, an average of all photographic B determinations was used.

The predicted B values and the measured B values for daytime are summarized in Figure 27, with all three meters represented. The line represents perfect agreement between measured and predicted B. There is considerable scatter, but no evidence for an overall systematic difference between the two quantities. The correlation between predicted and measured B equals 0.57. There is not a significant difference between the two distributions (CR_d equalling 1.8)

These data have been separated for each of the three meters. Figure 28 represents the Black Box data. The correlation equals 0.57, and there is not a significant difference; CR_d 1.2. Figure 29 represents the Loofah data. Correlation = 0.67, and there is not a significant difference; CR = 1.3. Figure 30 represents the Disappearance Range Gauge data. Correlation = 0.67, but there is a significant difference. CR_d = 5.8, indicating that D. R. G. systematically predicted too large a B.

Cross-comparison between the meters reveal the following results. (Figure 31) The Loofah and Black Box correlate 0.76, with CR = 0.66. (Figure 32) The Loofah and D. R. G. correlate 0.89, with a CR_d = 5.5, indicating that the D. R. G. predicts consistently higher B's than the Loofah. (Figure 33) Finally, the Black Box meter correlates with the D. R. G., r = .62; the data reveal

the higher B's predicted by the D. R. G. are of borderline significance, CR = 2.0.

In Figure 34 are given the four night determinations - note that the Loofah appears to predict B satisfactorily except for one condition in which visibility was restricted by precipitation.

For small targets such as we used, there is probably no reason to expect secondary scattering to be of important magnitude - if not, we might expect the Loofah to perform as satisfactorily at night as in the daytime.

It is interesting to observe that approximately equivalent mean values were obtained with each of the instruments. Both the Black Box and Loofah involve large sampling errors, whereas the DRG does not. The Loofah does not include the effects of absorption whereas the other meters do so.

All meters assume Koschmieder's law. The agreement between the mean value predicted by the meters and the measured value gives us an indirect verification of Koschmieder's law under a variety of "practical" situations.

We are apparently justified in accepting the principles underlying the Black Box meter and the "Loofah" as empirically equivalent and valid under the conditions tested. The D. R. G. is not equivalent to the others, nor valid, but the assumption of a slightly greater threshold value than 0.02 would bring the D. R. G. results into mean agreement with the other meters and with the criterion measure.

The D. R. G. was difficult to use on many occasions because of the limited number of landmarks. The "Loofah" is a thoroughly satisfactory device for practical use at fixed installations where power is available. It would appear that the possibility of constructing a practical Black Box photometer might be worthwhile, particularly for portable use where power is not available. Its use is restricted, of course, to daytime situations.

We may perhaps conclude that satisfactory principles are available upon which to base construction of a visibility meter. If the application of visual range predictions to field situations is of importance, it would appear that a feasible meter may be developed and the visibility nomographs may now be applied with reasonable confidence to predictions of the limiting visual range of certain relatively stationary targets. Feasibility of the meters under conditions of very restricted visibility needs further investigation.

DISCUSSION: (Subcommittee Meeting, March 3, 1949)

Mr. Middleton stated that all the tests at Roscommon had been made at relatively long visual ranges. Apparently, judging from the Roscommon results and from results reported by Waldram, the scattering function for visual ranges under seven miles are approximately constant, and it is for this reason that the Loofah apparently predicts beta accurately.

Mr. Middleton expressed his assurance that under conditions of very short visual range, the Loofah would begin to be in large error with respect to the true value of beta. Mr. Middleton also stated his belief that the Roscommon

tests indicate that sampling is not a serious problem under the conditions of test. Mr. Middleton believes, however, that under many conditions where polution exists, sampling errors would become quite large and that the Loofah would begin to include enormous errors from this cause also.

Dr. Tousey asked what Dr. Blackwell thought about the Disappearance Range Gauge.

Dr. Blackwell replied that the Dissappearance Range Gauge correlated relatively highly with the Loofah and with the photographic values of beta, but that it was not useful under many conditions because of insufficient range marks.

Commander Brown emphasized that the Roscommon tests make it possible for actual use of the Tiffany nomographic charts to be undertaken with confidence. He suggested that this fact not be obscured by petty discussions of small differences which had been obtained.

DISCUSSION: (Vision Committee Meeting, March 5)

Dr. Verplanck asked whether the laboratory studies of point source thresholds reported were new or whether they were the Tiffany data.

Dr. Blackwell replied that the data were collected newly on the observers used in the field tests. He mentioned, however, that the data on the four observers used in the field tests agreed with the Tiffany results within 7% at high brightness and within 25% at low brightness.

Dr. Hulburt expressed the appreciation of the Subcommittee to Dr. Blackwell for the research completed.

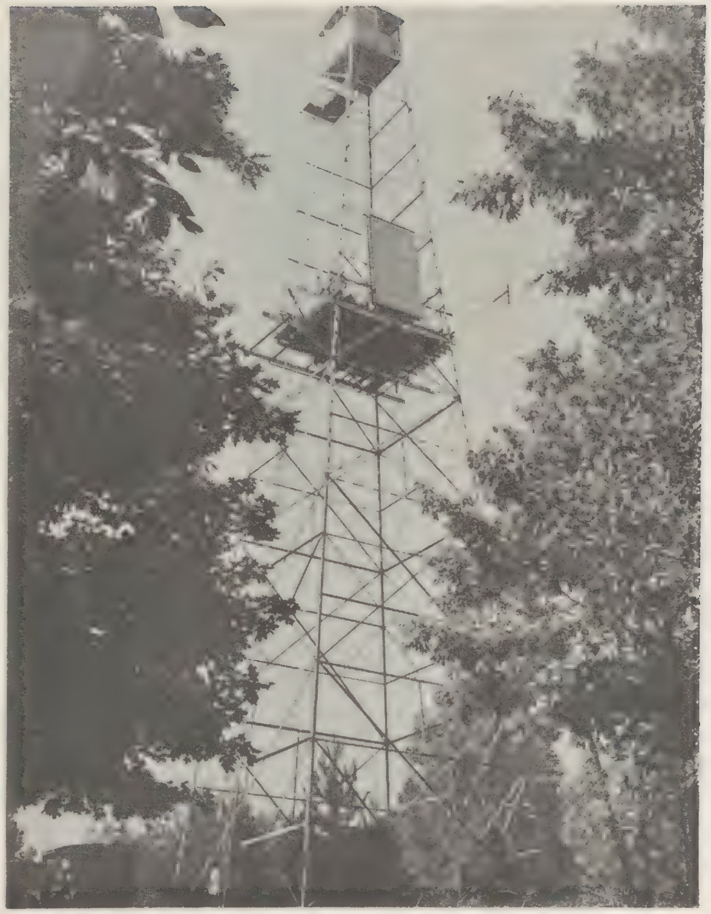


Figure 1

Figure 2

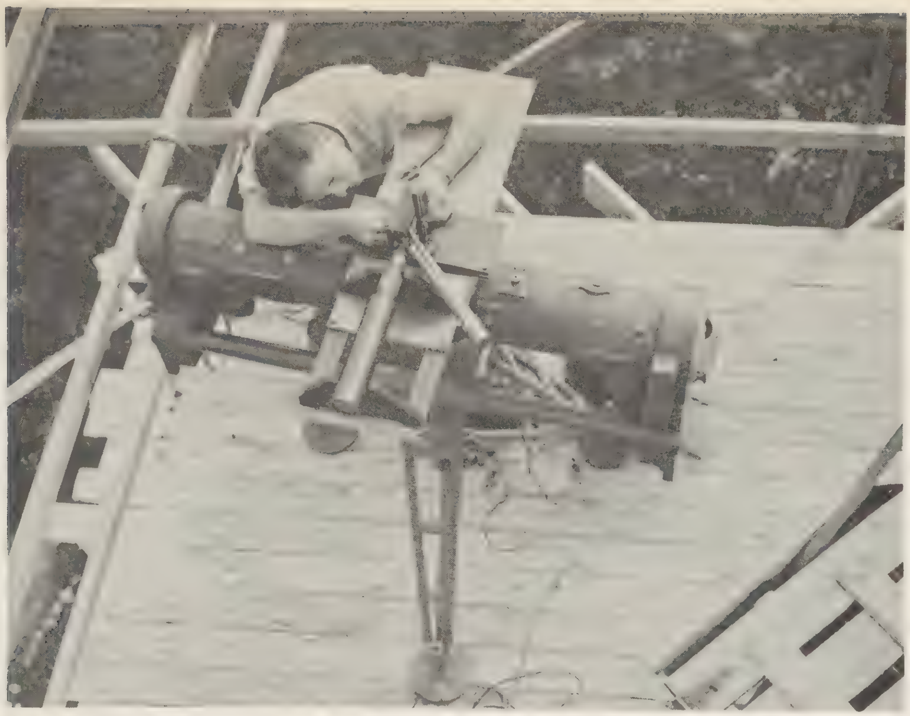
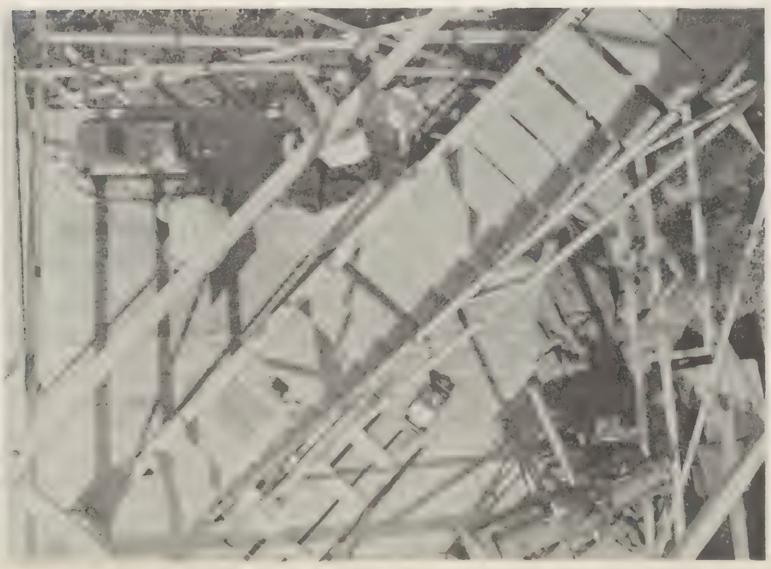


Figure 3

Figure 4



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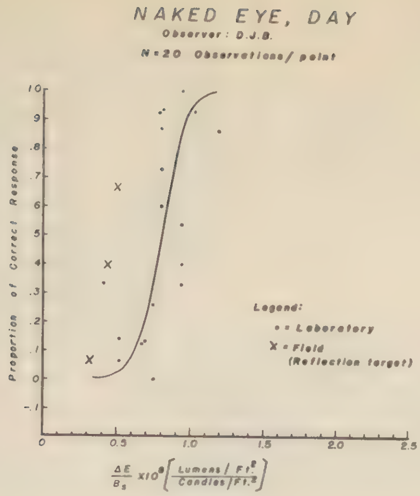

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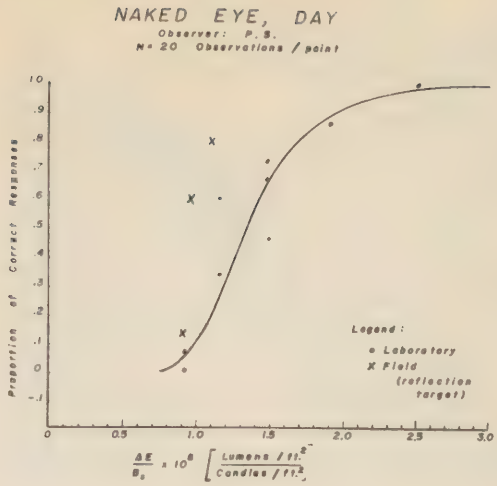

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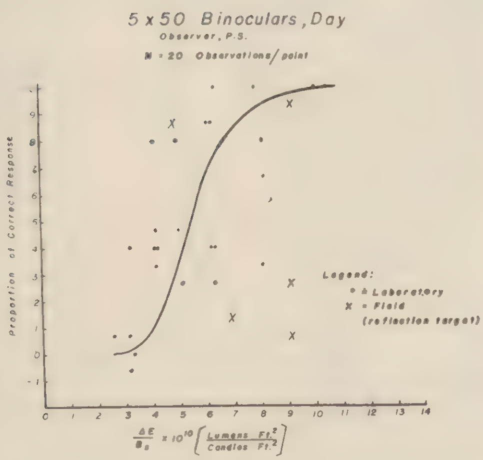

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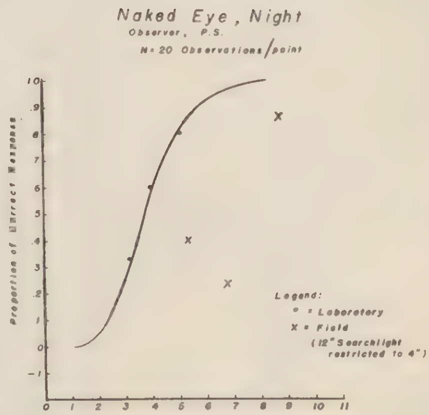

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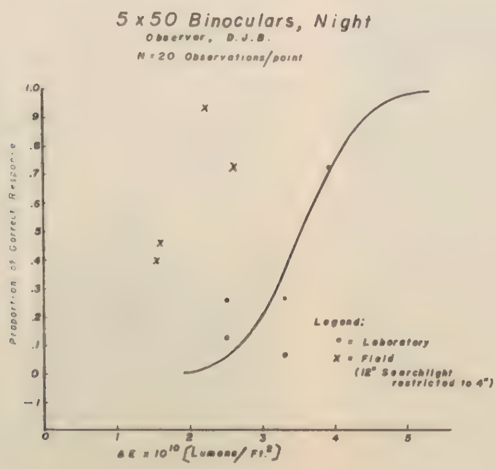


Figure 10.

Figure 11

Figure 12

Figure 13

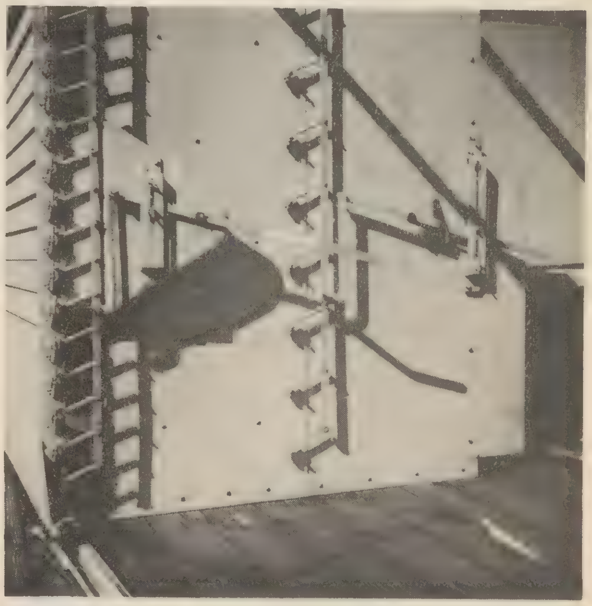


Figure 14

Figure 15

Figure 16

Figure 17

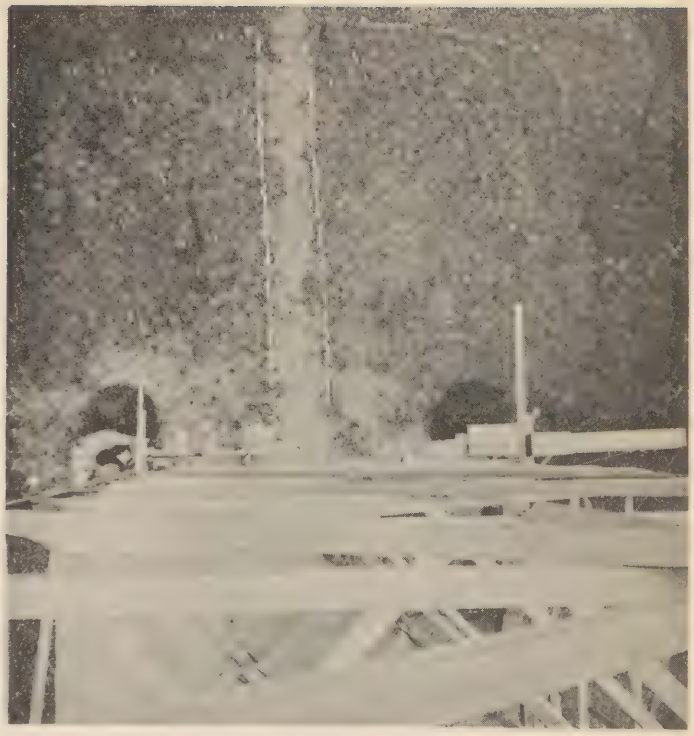
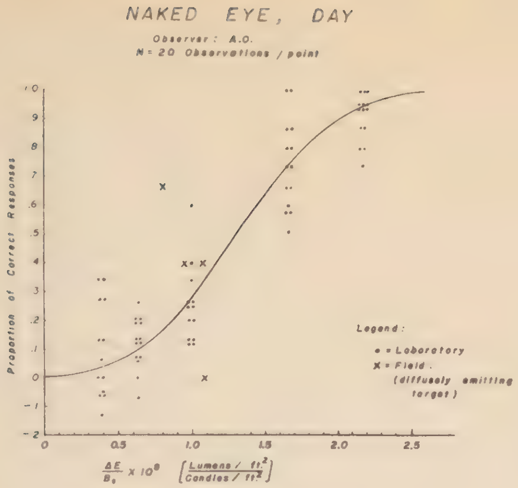


Figure 20

Figure 18

Figure 21

Figure 19



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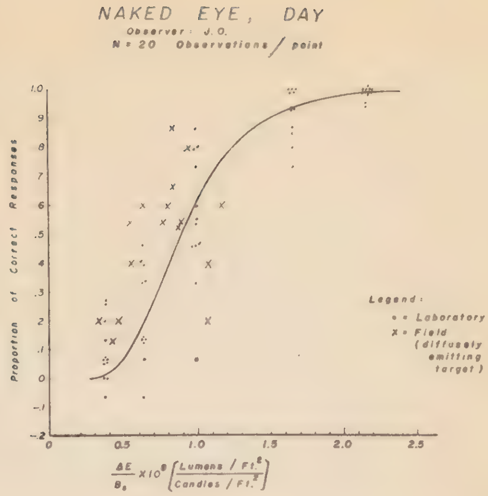

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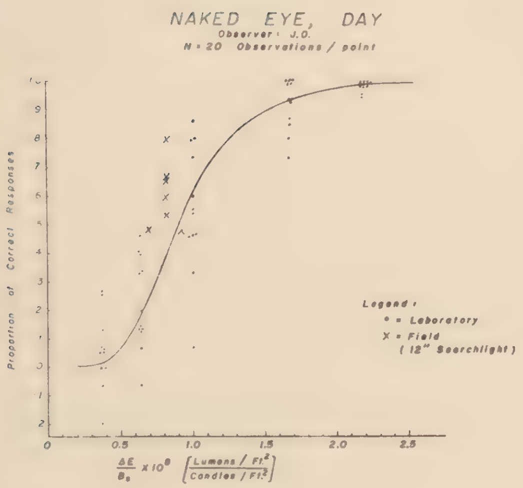

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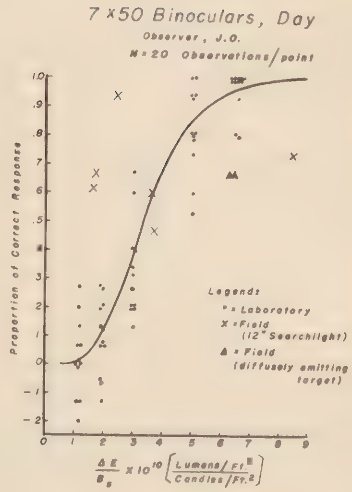

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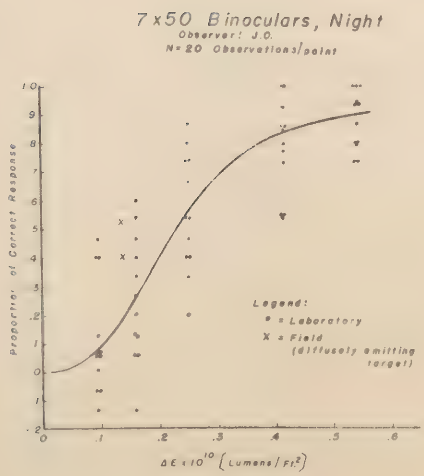

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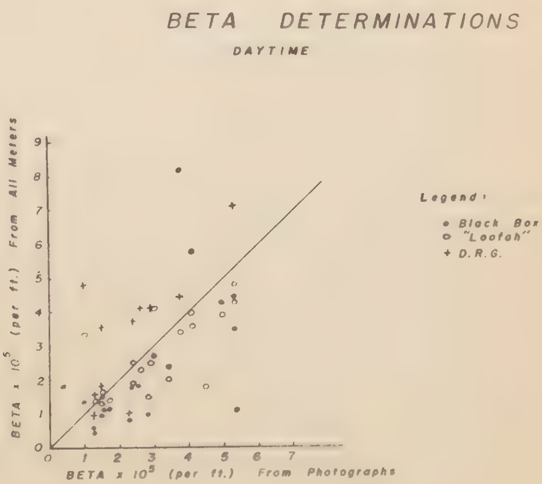
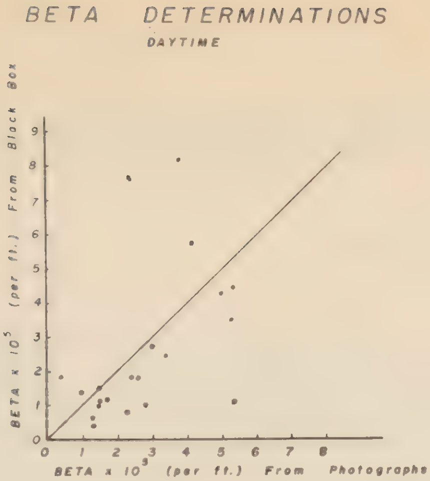


Figure 27.



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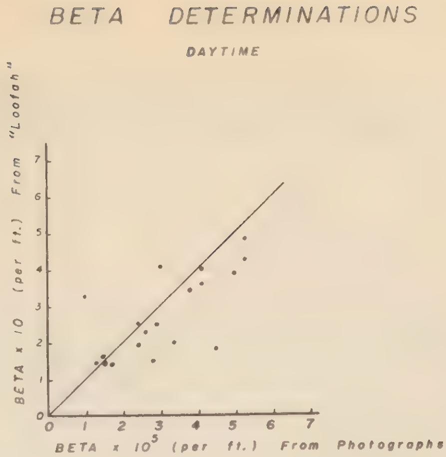

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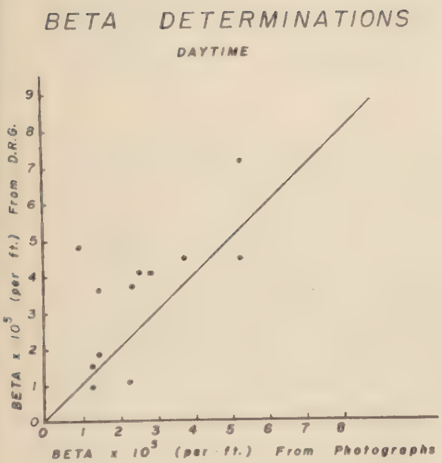

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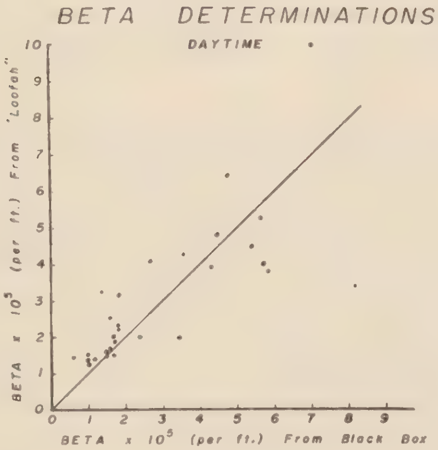
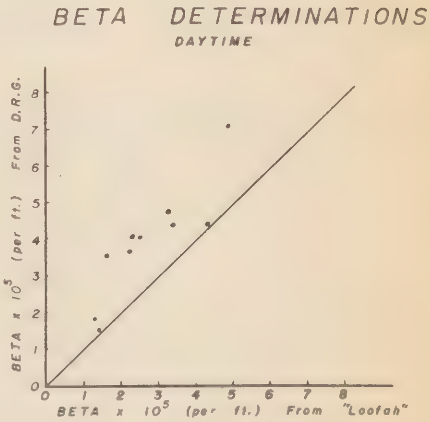


Figure 31.



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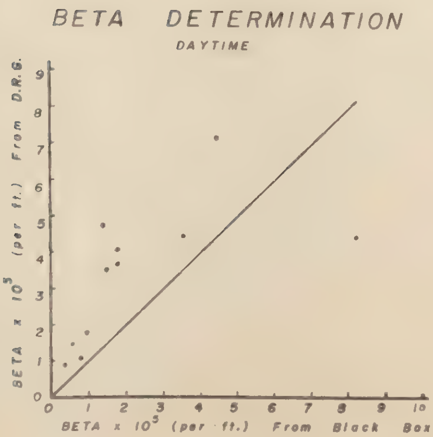

Figure 33.

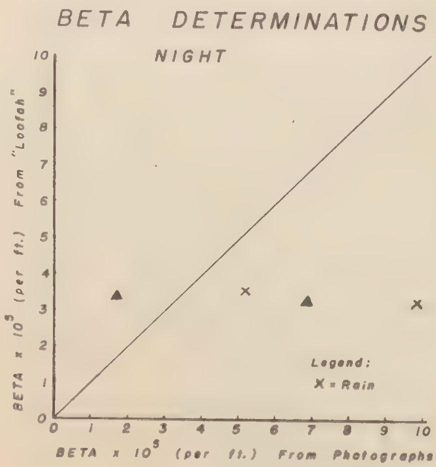

Figure 34.

INTERIM REPORT ON EXPLORATORY STUDIES OF THE PHYSICAL FACTORS WHICH INFLUENCE THE VISIBILITY OF SUBMERGED OBJECTS

S. Q. Duntley
Mass. Inst. of Tech.

An exploratory investigation of the physical factors which influence the visibility of submerged objects has been undertaken at the request of Section 2A3 of the Subcommittee on Visibility and Atmospheric Optics. This research was recommended by the Subcommittee in response to a request from the Navy for the advice concerning the detection ranges of submerged submarines under various conditions. It is the opinion of the Section that certain exploratory experiments should be conducted at model scale in convenient inland waters in order to identify the significant physical variables and to devise experimental techniques for measuring these variables in terms of parameters useful in visibility calculations. The Section feels that, upon the conclusion of these experiments, it may be able to recommend experimental procedures to be carried out at sea by the Navy in order to secure the basic data which will be required before the visibility of submerged submarines can be predicted.

Under a contract with the Office of Naval Research, the first of the experiments were conducted during the summer of 1948 at a temporary field station located on Diamond Island in Lake Winnepesaukee, New Hampshire. A tower was constructed near the south shore of this island in order to afford an observation post from which cameras and photometers could view vertically, objects submerged in comparatively deep water. The observing platform was approximately 30 feet above the water surface, and the water was approximately 20 feet deep. Photographic photometers in the tower were used to measure the apparent contrast of submerged objects, and the refractive distortions caused by the water surface were studied by means of motion picture photography. A horizontal rectangular panel 2 x 6 feet, painted with white, gray, and black squares, was moored at a depth of 10 feet directly beneath cameras in the tower. A number of smaller targets were moored in a circular pattern, the radius os which subtended an angle of 30° as seen by the cameras. All of these targets could be photographed simultaneously by means of a wide angle lens. A photometric gray scale mounted near the base of the tower appeared in all pictures in order to permit photographic photometry. Other cameras were mounted in a glass-bottomed boat moored to the base of the tower, and these cameras were used to measure the apparent contrast of the submerged object as seen from just beneath the surface of the water. Figure 1 shows the result of a series of four observations taken on a cloudless day. It will be noted that the apparent contrast seen by the observers in the tower was much less than that seen from the glass-bottomed boat. This reduction of contrast results from the reflection of the sky by the surface of the water. The factor by which the apparent contrast was reduced by this reflection is plotted in Figure 2. It will be observed that the four points fall on a smooth curve which is not symmetrical with respect to noon. The contrast reduction factor does not, therefore, correlate simply with the elevation of the sun. The surface of the water was glassy calm at the time of the first morning run, but became progressively rougher as the day wore on. It appears, therefore, that the contrast reduction factor is governed primarily by the state of the sea. Further studies have been planned to identify physically measurable parameters which will correlate with the contrast reduction factor. Apparatus for this purpose is now under construction and it will be tested at the field station during the summer of 1949.

During many of the experiments, an electric lamp was lowered into the water. Motion picture studies showed that the light was seldom seen as a single bright spot. It usually appeared as a multiple spot, but due to the motion of the surface of the water, the pattern changed continually. Studies of the motion picture records give information concerning the amplitude and frequency of the motion of the light and the magnitude and frequency of the apparent area of the water surface which image the lamp. These data are of fundamental significance because the image of every point on the surface of an extended object undergoes the same type of optical behavior as does the image of the lamp. It may be possible to analyze the observed refractive effects in such a manner that the apparent distortions of submerged objects can be correlated with the state of the sea. From the studies conducted thus far, it has been established that the outline of an extended submerged object is always sharp, although the rapidity of the apparent movement of the edge of the target often gives the visual impression of a blurred outline.

Motion picture studies of the distribution of the illumination on submerged objects were conducted by photographing a large white horizontal panel suspended beneath the glass-bottomed boat. When the panel was close to the surface rapidly moving bands of light passed over the target. As the depth of the panel was increased, however, the sharpness and the intensity of these bands diminished. When the panel was a few wavelengths deep the effect disappeared entirely. Corresponding observations were made using a vertical panel. It has been concluded that the illumination on the surface of a submerged submarine may be considered to be steady for the purposes of visibility calculations.

Another phase of the exploratory research centered around studies of the reduction of apparent contrast by water. For this work a barge was constructed which provided an underwater window through which an observer could view either horizontally or along inclined paths of sight. Attached to the barge was a floating boom from which five vertical targets were suspended as shown in Figure 3. The targets were arranged at 5 foot intervals from the window of the barge and each target subtended the same angle as viewed from the window. Both black targets and white targets were observed. It appears reasonable to expect that the reduction of contrast by water along horizontal paths of sight should follow the same laws which are observed to hold in the case of objects seen along horizontal paths of sight through the apmosphere. For example, when an object is viewed against the horizon, the apparent contrast decreases exponentially with distance and the attenuation coefficient is independent of the azimuth of the path of sight with respect to the sun. The data shown in Figure 4 demonstrates that the same laws hold along horizontal paths of sight through water.

The vision restricting properties of the atmosphere have been usefully described in terms of a quantity proportional to the reciprocal of the attenuation coefficient. This has been called the meteorological range, and it is defined as that horizontal distance within an optically homogeneous atmosphere for which the contrast transmittance is two percent. It is convenient to adopt a corresponding quantity to describe the vision restricting the properties of water. This will, henceforth, be termed the hydrological ranges* it is that horizontal distance through optically homogeneous water required to reduce the apparent contrast of any object to two percent of its inherent value. In Figure 4 the hydrological range is 45 feet.

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* This name was suggested by Mr. W. E. K. Middleton.

Inclined paths of sight through water were explored by depressing the floating boom by means of a weight and a float as shown in Figure 5. When the path of sight was inclined 30° downward, the data shown in Figure 6 were obtained. These data show that apparent contrast decreases exponentially with distance, but the attenuation is more rapid than that observed along horizontal paths of sight. A distance of approximately 30.5 feet has a contrast transmittance of two percent along this path of sight. This is 0.68 of the hydrological range, and the fraction 0.68 has been termed the <u>hydrological factor</u>.

Figure 7 shows a corresponding set of data for a path of sight inclined downward at an angle of 60°. The hydrological factor for this path of sight was found to be 0.49. In Figure 7 two kinds of apparent contrast are plotted. These are termed "edge contrast" and "absolute contrast" respectively. The former relates to the apparent contrast of the target relative to the apparent brightness of the background at the edge of the target, and the latter specifies the apparent contrast of the target relative to the apparent brightness of the field of view if the target were absent. It will be noted that the hydrological factor appears to be the same for both quantities. The data in Figures 5 and 6 refer to edge contrast.

Vertical paths of sight were explored by lowering a circular white target beneath the glass-bottomed boat. The results of this experiment are shown in Figure 8. An exponential decrease of apparent contrast was found. Very high apparent contrasts were observed during this experiment. The departure of the data from a straight line at the extreme top of the curve may be due to the shadow of the boat, but further exploration of this part of the curve is planned. The hydrological factor for the vertical path of sight was found to be 0.36. It will be noted that the hydrological factor decreases regularly as the path of sight becomes steeper.

In anticipation of the development of a theory of the reduction of apparent contrast along inclined paths of sight through water, luminous density was measured at various depths. The data are shown in Figure 9. It will be noted that luminous density decreases exponentially with depth.

Plans for a continuation of this research include the construction of instruments for measuring various aspects of the state of the sea, the state of the sky, and the state of the water in the hope of discovering measurable physical parameters which will correlate with the vision restricting properties of the sea. These instruments will be tested, modified, and re-tested at the field station during the summer of 1949. On the basis of this experience, apparatus for research at sea will be prepared during the winter of 1949-50. After the range of the variables have been ascertained by experiments at sea, and after any required special properties of human vision have been measured, it may be possible to predict the visibility of submerged objects of any kind under virtually any circumstances.

[redacted]

DISCUSSION: (SubCommittee Meeting, March 3)

Commander Brown stated his appreciation for the work conducted by Dr. Duntley. He expressed his great satisfaction in seeing new principles developing which would make sense out of observations of submerged objects.

Commander Brown suggested that the Subcommittee urge continuance of Dr. Duntley's work.

DISCUSSION (Vision Committee Meeting, March 5)

Dr. Hardy suggested that one simplified assumtion could be made since submarines are large objects and therefore do not exhibit edge fluctuations of the sort shown to exist by Dr. Duntley. Since the submarines are normally far under the surface, illumination gradients do not exist, so that the chief effects are the absorption and scattering of light in the water itself and the reduction of contrast due to reflected sky light.

Dr. Duntley expressed his agreement with Dr. Hardy's conclusion that illumination gradients do not exist under practical submarine sighting conditions, but questioned Dr. Hardy's suggestion that the edge phenomena are not of importance.

Dr. Duntley expressed his belief that the edge phenomena depended upon an invarient relationship between the size of the object and the wavelength of the wave structure.

After discussion the Vision Committee approved the following resolution concerning Dr. Duntley's project:

THE VISION COMMITTEE EXPRESSES ITS CONFIDENCE IN THE STUDIES OF OPTICAL PROBLEMS OF WATER SURFACE, BEING CONDUCTED BY PROFESSOR S. Q. DUNTLEY AT MASSACHUSETTS INSTITUTE OF TECHNOLOGY, AND EXPRESSES ITS HOPE THAT THE WORK CAN BE CARRIED TO COMPLETION.

[redacted]

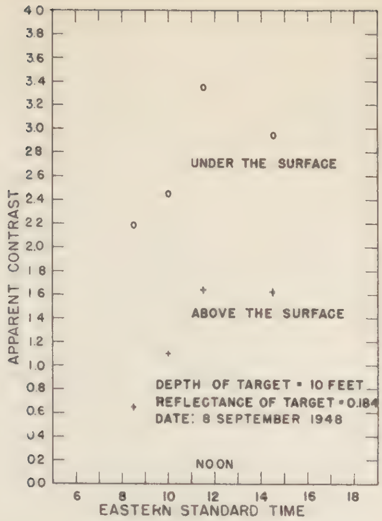

Figure 1

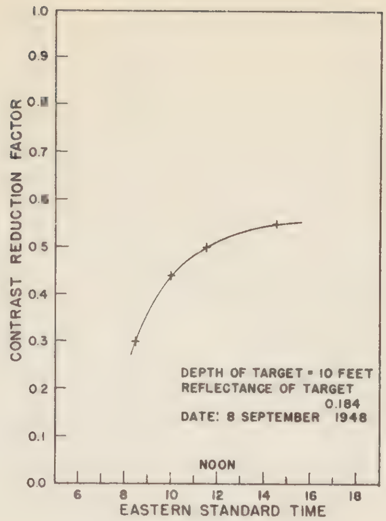

Figure 2

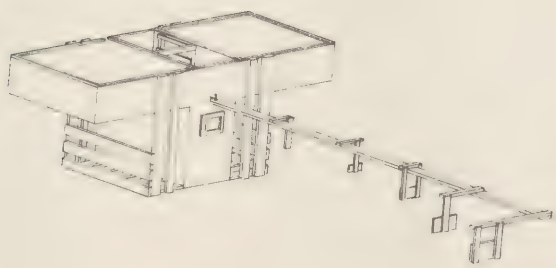

Figure 3

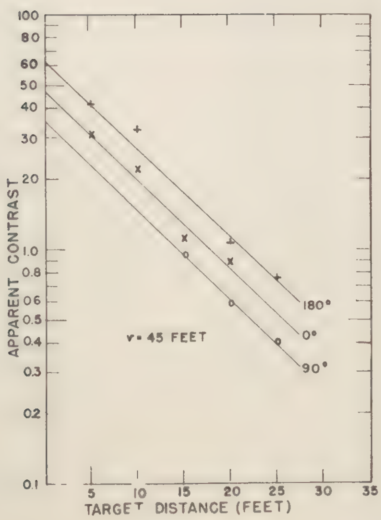

Figure 4

Figure 5

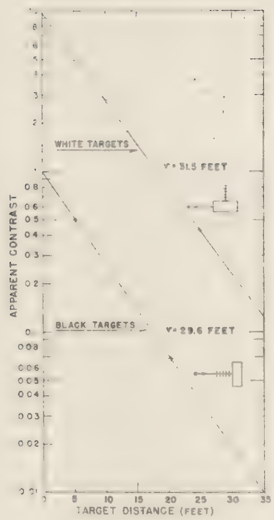

Figure 6

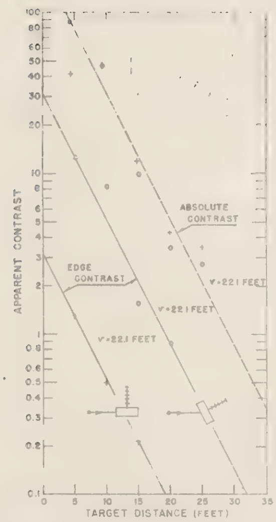

Figure 7

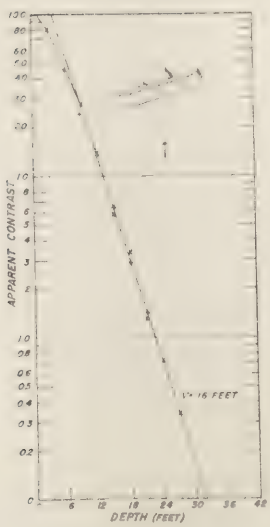

Figure 8

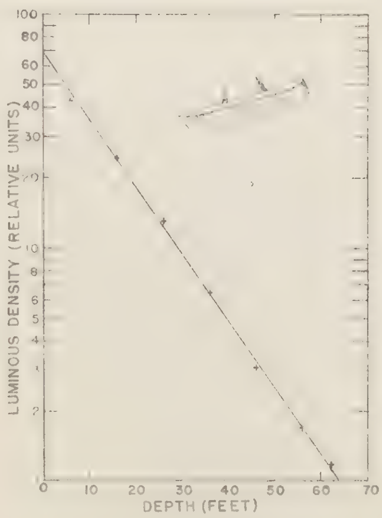

Figure 9

ESTIMATES OF VISIBILITY FROM HIGH ALTITUDE AIRCRAFT*

Dr. Jesse Orlansky

1. Introduction

It is desirable to know what may be seen from a plane in high speed flight at very high altitude. High speed implies that unpursued targets remain visible for relatively short times. On the other hand, high speed will probably require operation at rather high altitudes and at these altitudes a target may be visible at unusually great distances. Evaluation is, therefore, desireable. The specific question considered in this report is, "For various combinations of observer and target altitudes, how far away can a pilot see another object, such as a plane, in the sky?".

An approximate answer may be given to this question by recourse to information already reported in the literature. Since a large number of factors determine what can be seen by a human observer, it is convenient, whenever possible, to simplify the problem by eliminating certain specified variables. Visibility, as it is considered here, is measured by the extreme distance at which the mere presence of another object may be detected in a variety of viewing circumstances. The distances at which an object may be recognized and identified are not considered here. Of course, it is known that the distance at which identification is possible is less than that at which an object becomes just visible. Furthermore, the threshold of visibility is defined in this report at the 50 percent level of probability. A correction can readily be made if one wishes to adopt some other level of probability.

The problem is further simplified by assuming that the observer is unencumbered in any manner and that both the observer and the target are motionless with respect to each other. It is recognized that visual problems related to high altitude flight may result from such optical influences as glare and image distortion due to shock waves and from such physiological influences as anoxia, temperature, vibration, g, and fatigue (9, 17, 18). However, to repeat, visibility in this paper is considered for the normal pilot free from any special stresses. This simplification and the one with regard to motion are due in part to the lack of satisfactory information. Further studies will be necessary to show the effects of removing these strictures.

Still other basic simplifying assumptions, which are commonly made, should also be mentioned. These are related to the visual angle, the target shape, and the adaptation level. The visual angle is assumed to be constant, regardless of distance (2, 8). A circular target is used as the basis for calculations and the evidence indicates that estimates based on such a target would also hold, with negligible error, for other compact targets of equal area though different shapes (15, 16). With regard to adaptation level, it is assumed that the observer is adapted to the brightness level at which visibility is considered. This means that for night viewing conditions, it is assumed that 30 minutes have elapsed or that the subject has been dark-adapted with red goggles prior to flight.

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*This paper is based on Report No. 151-1-14 (Confidential), dated 15 Apr. 1948, submitted to the Office of Naval Research, Sands Point, Port Washington, L.I., N.Y., on Contract No. N6ori-151 with The Psychological Corporation. The authors of that report are L. Festinger, H. H. Kelley, J. Orlansky and J. D. Coakley.

The basic data for the relation between contrast and target area are taken from the article by Blackwell entitled, "Contrast Thresholds of the Human Eye" (3). These data are, of course, more substantial than any other existing laboratory data. However, they were checked and found in general agreement with other sources. They are also close to certain field trial data (5, 10), though the discrepancies are not large.

Figure 1, which is reproduced from Blackwell's paper, shows graphically the well-known relationship between brightness contrast and target area. These data will be referred to again later, but for now a glance at Figure 1 will show that the least amount of contrast is required for perception of a large target at high brightness levels; the greatest amount of contrast is required for small targets at low brightness levels.

2. Intermediate Calculations and Results

It is now necessary to consider certain intermediate calculations which were made to reach the final estimates of visibility. These concern, briefly, (1) the maximum geometric viewing distances for three different directions of view; (2) the visibility of a target before corrections have been made for atmospheric effects; and, finally, (3) the effects of the atmosphere on visibility.

Figure 2 shows the absolute geometric limits of visibility for three different directions: 1) the downward line of sight, which represents the observer's altitude and the closest distance to the earth, 2) the line of sight tangent to the earth's surface which is the maximum distance at which another object, at some particular altitude, could be seen without having the earth block the view, and 3) the line of sight tangent to 30,000 feet, chosen to represent the level above which atmospheric attenuation can be virtually ignored. At 110,000 feet, the line of sight tangent to the horizon extends approximately 410 miles; and, at the same altitude, the line of sight tangent to 30,000 feet is 350 miles long. The attentive observer will note that this figure with a top at 200,000 feet (38 miles) was constructed when the tentative table for the upper atmosphere extended to 100,000 feet. Recently, we learn that a two-stage rocket has risen 250 miles or approximately 1,300,000 feet.

In Figure 3, Blackwell's data (3) have been used to plot the threshold visual angle against background or adaptation brightness for targets of various brightnesses. This type of graph does not make it necessary to compute contrast. The conditions described in Figure 3 are:

background brightness	-	0.00001	to 10,000 fl
target brightness	-	0.01	to 10,000 fl
target size	-	0.1	to 100 minutes of arc.

Suppose, for example, that a target with a brightness of 1000 fl appears against a sky brightness of 100 fl. The threshold visual angle is then about 0.14 minutes of arc. This is equivalent to a distance of approximately 22 miles for an object with a 10 foot diameter. Two other scales are provided to translate visual angle into distance for targets of 50 and 200 feet diameter.

Figure 3, of course, cannot be employed to estimate actual visibility except in the special case where there is no atmospheric attenuation. Since, however, atmospheric attenuation is an important determinant of visibility, the data presented in this figure must be modified to take account of atmospheric effects.

The atmospheric conditions which require attention are those which have an effect on light and consequently on the visibility of targets. The density of the air and the presence of impurities such as water vapor and dust are the major causes of atmospheric effects. The ultimate effect is a reduction of contrast.

The data that exist indicate that air density decreases in an exponential manner with increase in altitude (22). Less is known about the relation between the impurities in the air and altitude. However, Beta, the coefficient of atmospheric attenuation, expresses their combined effect upon the transmission of light; and Beta has been found to decrease with an increase in altitude.

Representative Beta values have been determined for four layers of the atmosphere up to 30,000 feet and for one layer above that level (6, 7, 12). The effects of atmospheric attenuation on contrast are demonstrated graphically in Figures 4, 5, 6, and 7. These figures show the manner in which brightness contrast is reduced with the passage of light through the atmosphere in four different directions of view (90°, 60°, 30°, and 0° to the earth's surface) for four selected altitudes (200,000, 100,000, 50,000, and 30,000 feet). As may be expected, the attenuation of brightness contrast, expressed as a percent of the original contrast, increases as the slant path passes through greater distances in the lower atmosphere. The greatest loss for a given distance occurs for the vertical line of sight, that is, the one to make an angle of 90 degrees with the surface of the earth. The smallest loss per unit distance occurs, naturally, for the line of sight tangent to the earth's surface for altitudes above 30,000 feet.

There is excellent agreement in the literature (14, 20, 21) concerning solar illumination. A conservative value of 12,000 footcandles is used in the present calculations to represent the maximum solar illumination. Scattered light is disregarded as a factor at high altitudes.

The brightness of the sky is, of course, another important factor in determining the brightness contrast of an object seen against it. It also determines the adaptation brightness or sensitivity level of the observer's eyes (14, 20, 21).

An analysis was made of the measurements of sky brightness given by various investigators (4, 5, 11, 13, 14, 19, 20, 21, 23, 24). It would be desirable to get some "standard" data, even though it is clear that sky brightness varies with such factors as position of the sky, time of day, season, and altitude, as well as with weather conditions. Speaking generally, sky brightness, except for that of the horizon, decreases with increases in altitude.

From the work of Teele (20) and Miley and McClellan (19), it is evident that sky brightness is directly proportional to the pressure exerted by the atmosphere. The findings of these authors are given in percent terms with sea level as 100 and with a regular decrease with increase of altitude. There are two problems which exist with respect to the facts. What sky brightness values should be taken to represent the base at sea level; and what measures have been taken from various altitudes to confirm the reduction of sky brightness? Many measurements at sea level are available (13, 14); a few have been made at moderate altitudes (4, 11, 21). According to one source, the maximum <u>average</u> sky brightness at sea level is about 1750 fl for the zenith, 3250 for

45° above the horizon, and 7000 fl for 2° above the horizon (21). Higher and lower values may be observed almost at choice, depending upon the specific viewing conditions. The observations taken at various altitudes leave no doubt about a proportional reduction of brightness with decrease of air pressure (i.e., increase of altitude), but the real question is what values should be taken to represent the sky at sea level and at altitude.

Since this paper is concerned with high altitudes, a range of values has been selected to represent the probable sky brightness that will be encountered there. The assumption is made that sky brightness varies from log 0 to log 1.5 footlamberts (1 to 31.6 footlamberts). The choice of log 1.5 footlamberts as a reasonable estimate of high brightness background does not forfeit much accuracy if the actual background is brighter because the contrast threshold is relatively constant at these and higher adaptation brightnesses (See Figure 1). The value of log 0 footlambert as the lower level of background brightness for daylight appears reasonable for many conditions except possibly for that part of the sky which is directly overhead.

We may now return to target brightness, remembering that maximum solar illumination is taken as 12,000 footcandles. Since the reflectivity of an airplane would probably not be greater than 80 or less than 3 percent, the target brightness range may extend from 360 to 9600 footlamberts. Speaking generally, targets are brighter than the background. If the brightness of the background ranges from 1 to 100 footlamberts, then contrast for the low reflectivity target may range from 359 to 2.6 and for the high reflectivity target from 9599 to 95. However, the contrast of a very bright target against a very dark background may not actually occur. The very dark background presupposes that the target is well over the head of the observer, while the maximum target brightness requires that the target be at a level with or below the observer. Therefore, the further calculations are based on what appears to be a reasonable compromise in which the contrast ratios have been assumed to range between 1 and 100.

3. Estimates of Visibility

The final results of these calculations, which incorporate the several facts and assumptions just discussed, are shown in Figures 9, 10, 11, and 12. Viewing positions at altitudes of 200,000, 100,000, 50,000 and 0 feet have been selected for presentation. The figures have been drawn to the same scale on both axes so that distance in any direction may be read with the aid of a ruler. The curved line at the bottom of the figures represents the curvature of the earth's surface. It has been assumed that the earth is a perfect sphere whose radius is 3958.89 miles. Visibility has been estimated for a circular target with a diameter of 10 feet. This dimension is taken to represent an approximation of current rocket propelled aircraft that may eventually operate at very high altitudes (1). Separate computations have been made for conditions when this target exhibits inherent contrast values of 1, 5, 10 and 100. Visibility is shown for each of these contrast values when the adaptation brightness is log 1.5 to log 0 footlamberts. The figures have been drawn in this form even though the contrast ratio of the target against its background will not be constant for all positions of azimuth. The brightness of the background and of the targets will vary with azimuth because of changes in position with respect to the sun. Thus, the visibility threshold for any given flight path may cut across several of the brightness contrast curves in Figures 9 to 12.

Comparison of these figures shows that visibility improves as altitude increases because the effect of atmospheric attenuation for a given distance along a particular line of sight is less when the observer is at a higher altitude. There are, however, two factors not directly evident in this form of graph which may improve visibility at high altitudes even more than the graphs suggest. These are the changes in contrast ratio as the altitude increases and as the target appears closer to an overhead position in the dome of the sky. The sky, obviously, becomes darker with an increase in altitude and with a more zenith position; and, thus, generally, the contrast ratios will become greater. The exact effect of these factors cannot be determined until there is more complete knowledge of illumination conditions at high altitudes.

Another point that should be made is that for an observer at high altitude the appearance of a target is very different from that at sea level. Since the source of light at sea level is from above, a target seen against the sky will be darker than its background. Such contrast ratios will consequently be less than 1, and contrast ratios as high as +5 will rarely be found. Visibility from sea level generally falls inside the curve for contrast ratios equal to 1. At high altitudes, however, a target will often appear to be brighter than its background. Contrast values may be expected to be high and greater than 1.

The graphs show that, compared to the surface of the earth, the range of visibility will be much greater at high altitudes. Visibility increases markedly with the reduction of atmospheric interference as altitude increases above sea level to about 50,000 feet. Thus, visibility also increases with the increased contrast between target and background, due primarily to reduction of background brightness with illumination remaining about constant, as altitude increases.

Although the visibility shown in Figures 9 to 12 is great when compared to that found at the surface of the earth, the distances must be related to the speed at which the pilot may be travelling. Figure 13 is offered to facilitate the conversion of distance into time at several speeds. Suppose, for example, an observer at 50,000 feet sights another target at extreme range and at the same altitude. Assume a contrast ratio of 10 and a sky brightness of log 1.5 footlamberts. For these conditions, Figure 12 shows that the limit of visibility is about 38.8 miles. Suppose, further, that the target is a missile travelling directly toward the observer at 1000 mph and that the observer's plane is moving toward the target at 1000 mph. The rate of closing, then, is 2000 mph. Reference to Figure 13 shows that about 71 seconds are required to cover 39 miles at a rate of 2000 mph. This is the largest time that would be available for a collision course at these speeds because it has been assumed that the target is seen by the observer as soon as the limit of visibility has been reached. When adjustments are made for the visual search procedure used by the pilot, his degree of alertness in the sector of the target and the unlikelihood of a quick response to a "faint hunch" in lieu of a clearly visible target, it is likely that 71 seconds will no longer remain. Possibly, even higher speeds may be encountered than those considered here, in which case the time available to the pilot decreases further from the values given in the example. No allowance has been made for the possible requirement that the pilot maneuver his plane to an attacking (or defending) position after another object has been sighted. Such maneuvers take time and also introduce another group of factors concerning the flight paths which are permissible within human and mechanical limits at such speeds.

Thus, our calculations indicate that relatively long range visibility will be possible at high altitudes. However, in terms of an actual flight situation, it is obvious that a very short time is available for dealing with objects which appear in the visual field. It will be well to maintain an open mind concerning the significance of these facts in military situations.

Bibliography

1. Anonymous. Aeronautical Engineering Review, 1947, 6(1), 38; (3), 45, 74.
2. Beebe-Center, J. G., Mead, L. C., Wagoner, K. S., and Hoffman, A. C. Visual acuity and distance of observation. J. Exp. Psychol, 1945, 35, 473-484.
3. Blackwell, H. R. Contrast thresholds of the human eye. J. Opt. Soc. Amer., 1946, 36, 624-643.
4. Christensen, J. M. Some typical sky and earth brightnesses at altitudes 10,000 to 40,000 feet and their relation to the eye-adaptation problems of the radar operator. Memo. Report TSEAA-694-11, A.A.F. Hdqtrs., Air Mat. Comm., Eng. Div., Aero Med. Lab. 9 December 1946.
5. Coleman, H. S. and Verplanck, W. S. A comparison of computed and experimental detection ranges of objects viewed with telescopic systems from aboard ship. J. Opt. Soc. Amer., 1948, 38, 250-253.
6. Duntley, S. Q. The reduction of apparent contrast by the atmosphere. J. Opt. Soc. Amer., 1948, 38, 179-191.
7. Duntley, S. Q. The visibility of distant objects. J. Opt. Soc. Amer., 1948, 38, 237-249.
8. Forbes, T. W. and Holmes, R. S. Legibility distances of highway destination signs in relation to letter height, width, and reflectorization. 19th Annual Meeting Highway Research Board, December 1939, 321-335.
9. Hecht, S., Hendley, C. D., Frank, S. R., and Haig, C. Anoxia and brightness discrimination. J. Gen. Physiol., 1945, 29, 335-351.
10. Hecht, S., Ross, S., and Mueller, C. G. The visibility of lines and squares at high brightnesses. J. Opt. Soc. Amer., 1947, 37, 500-507.
11. Hommel, R. W. Sky brightness. Memo. Report TSEPE-673-107K, A.A.F., Air Mat. Comm., November 1946.
12. Hulbert, E. O. The upper atmosphere of the earth. J. Opt. Soc. Amer., 1947, 37, 405-415.
13. Ives, J. E. and Knowles, F. L. Recent measurements of the brightness of the clear north sky in Washington, D. C. Trans. Illum. Eng. Soc., 1935, 30, 281-292.
14. Jones, L. A. and Condit, H. R. Sunlight and skylight as determinants of photographic exposure. I. Luminous density as determined by solar altitude and atmospheric conditions. J. Opt. Soc. Amer., 1948, 38, 123-178.
15. Lamar, E. S., Hecht, S., Shlaer, S., and Hendley, C. D. Size, shape, and contrast in detection of targets by daylight vision. I. Data and analytical description. J. Opt. Soc. Amer., 1947, 37, 531-545.
16. Langstroth, G. L., Wolfson, J. L., Batho, H. F., McLaren, E. H., McLeod, M. J., and Wong, W. G. A survey of visibility limen data. Project C. E. 128, Dept. of Physics, University of Manitoba, Winnipeg, Manitoba, 18 January 1945.

17. McFarland, R. A. Human factors in air transport design., New York: McGraw-Hill, 1946.
18. McFarland, R. A., Roughton, F. J. W., Halperin, M. H., and Niven, J. I. The effects of carbon monoxide and altitude on visual thresholds. J. Aviat. Med., 1944, 34, 319-329.
19. Miley, H. A. and McClellen, D. F. Sky brightness measurements from rocket borne equipment. J. Opt. Soc. Amer., 1947, 37, 994 (Abstract).
20. Teele, D. Insolation, earth, and sky brightness. National Geographic Magazine, Stratosphere Series, No. 2, 1936, 133-138.
21. Tousey, R. and Hulburt, E. O. Brightness and polarization of the daylight sky at various altitudes above sea level. J. Opt. Soc. Amer., 1947, 37, 78-92.
22. Warfield, C. N. Tentative tables for the properties of the upper atmosphere. Technical Note No. 1200, NACA, Washington, D. C., Jan. 1947.
23. Yeager, C. E. I flew faster than sound. N.Y. Herald Tribune, 22 August 1948, Section VIII, 6-7, 16.
24. National Geographic Magazine, Stratosphere Series, No. 1, 1935 and No. 2 1936.

DISCUSSION:

Dr. Hulburt remarked that when observing from an aircraft at high altitude, in the downward direction, objects will be seen against the earth brightness rather than the low brightness attributed by Dr. Orlansky to the sky.

Dr. Orlansky agreed with Dr. Hulburt, but pointed out that the angular subtense of the earth at high altitudes is somewhat restricted so that a sizeable portion of the field looking downward has the brightness of the sky.

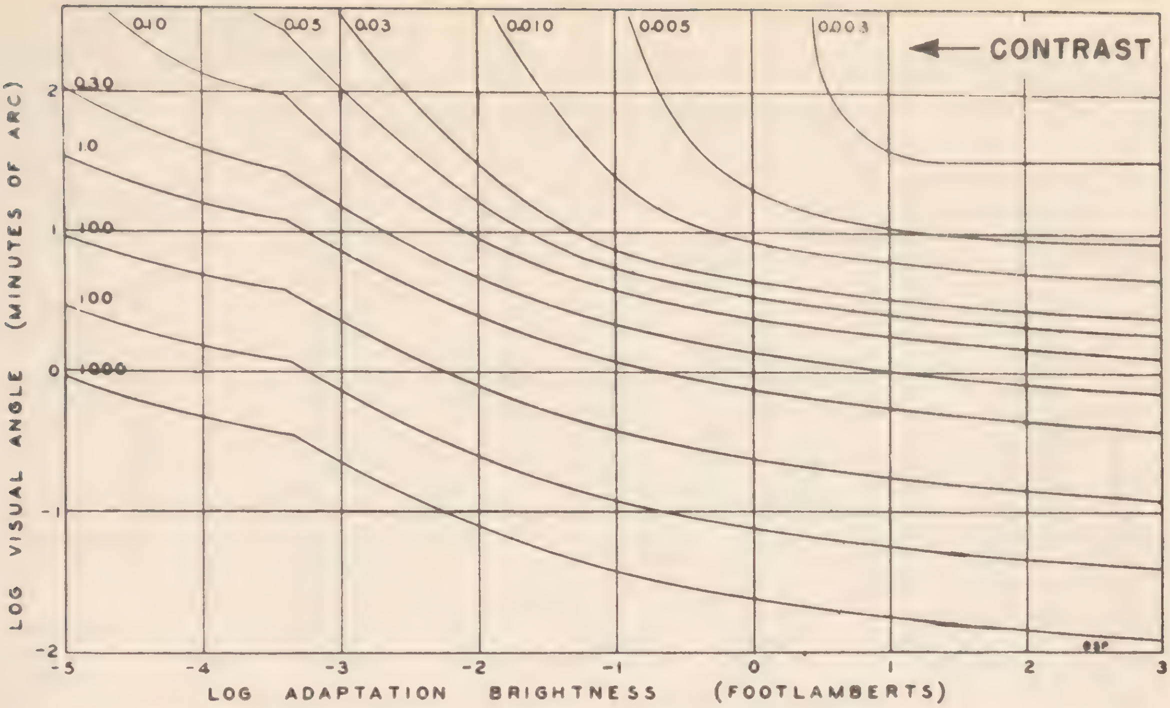

FIG. I THE RELATION BETWEEN STIMULUS AREA AND ADAPTATION BRIGHTNESS FOR STIMULI OF VARIOUS CONTRASTS. (FROM BLACKWELL (5), FIG. 18)

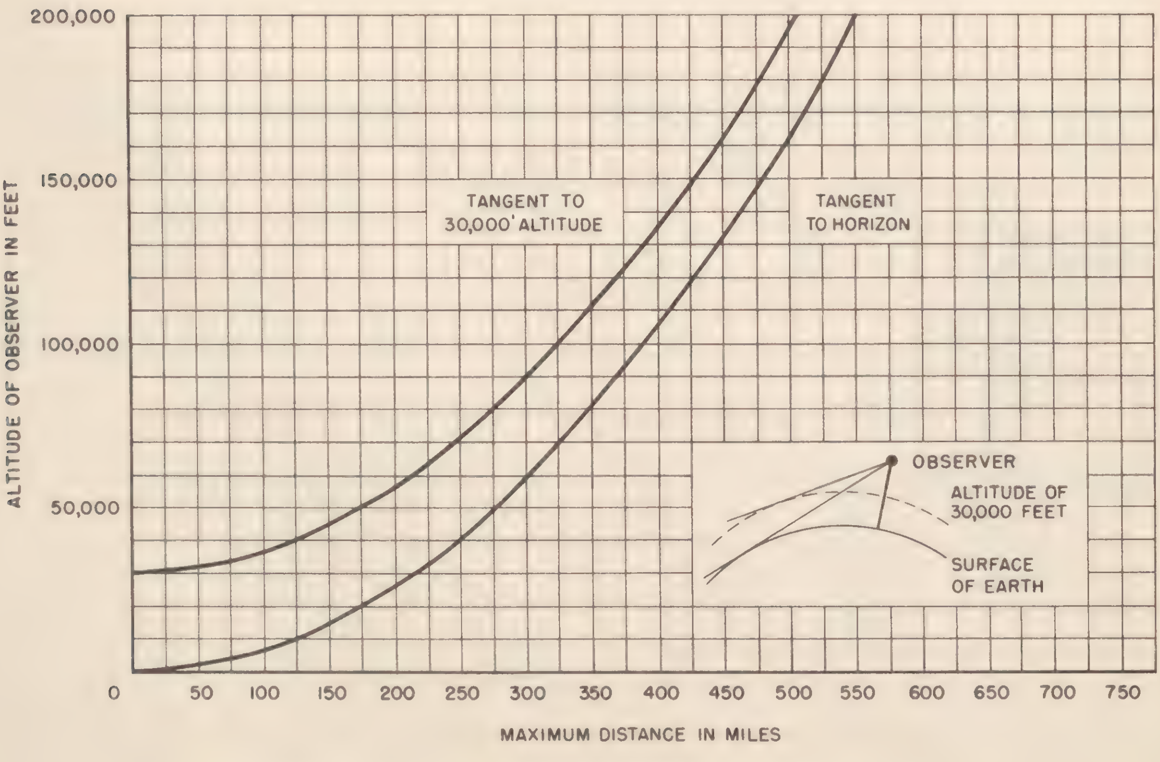

FIGURE 2: RELATION BETWEEN ALTITUDE AND MAXIMUM VIEWING DISTANCE TO THE HORIZON AND TANGENT TO A CIRCLE AT 30,000 FEET ALTITUDE

EQUIVALENT DISTANCE IN MILES FOR 3 ROUND TARGETS		
DIAMETER (FT.)		
10	50	200
.03	.16	.65
.05	.24	.96
.07	.35	1.41
.10	.51	2.07
.15	.76	3.03
.22	1.11	4.45
.33	1.63	6.53
.48	2.41	9.58
.70	3.51	14.09
1.03	5.14	20.66
1.51	7.55	30.34
2.22	11.08	44.50
3.26	16.3	65.3
4.8	24.1	95.8
7.0	35.1	140.9
10.3	51.4	206.6
15·1	75.5	303.4
22.2	110.8	445.0
32.65	163.0	653.0
48.0	241.0	958.0
70.0	351.0	1409.0
103.0	514.0	2066.0
151.0	755.0	3034.0
222:0	1108.0	4450.0
326.5	1630.0	6530.0

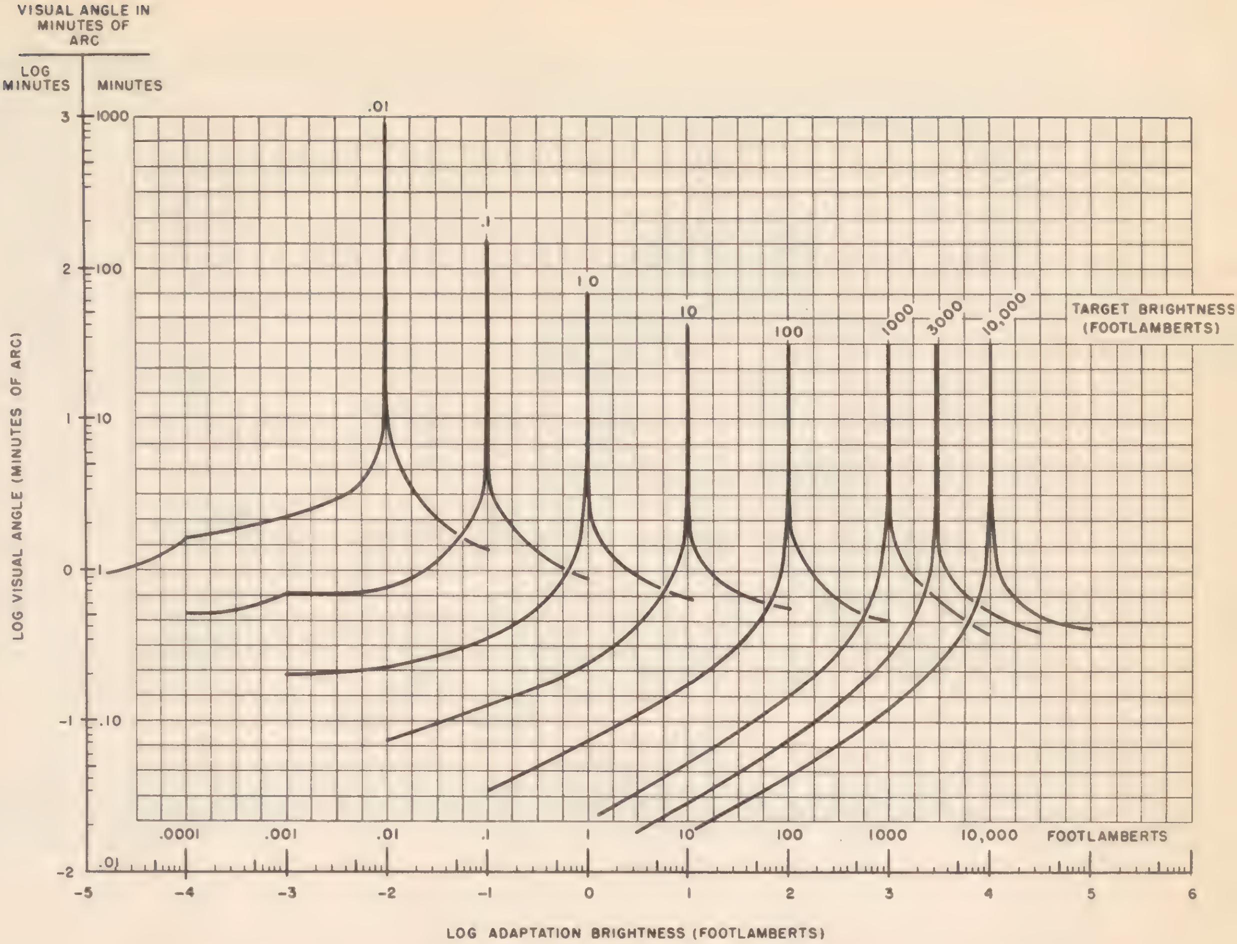

FIGURE 3: RELATION BETWEEN ADAPTATION BRIGHTNESS AND THRESHOLD VISUAL ANGLE FOR TARGETS OF VARIOUS BRIGHTNESSES.

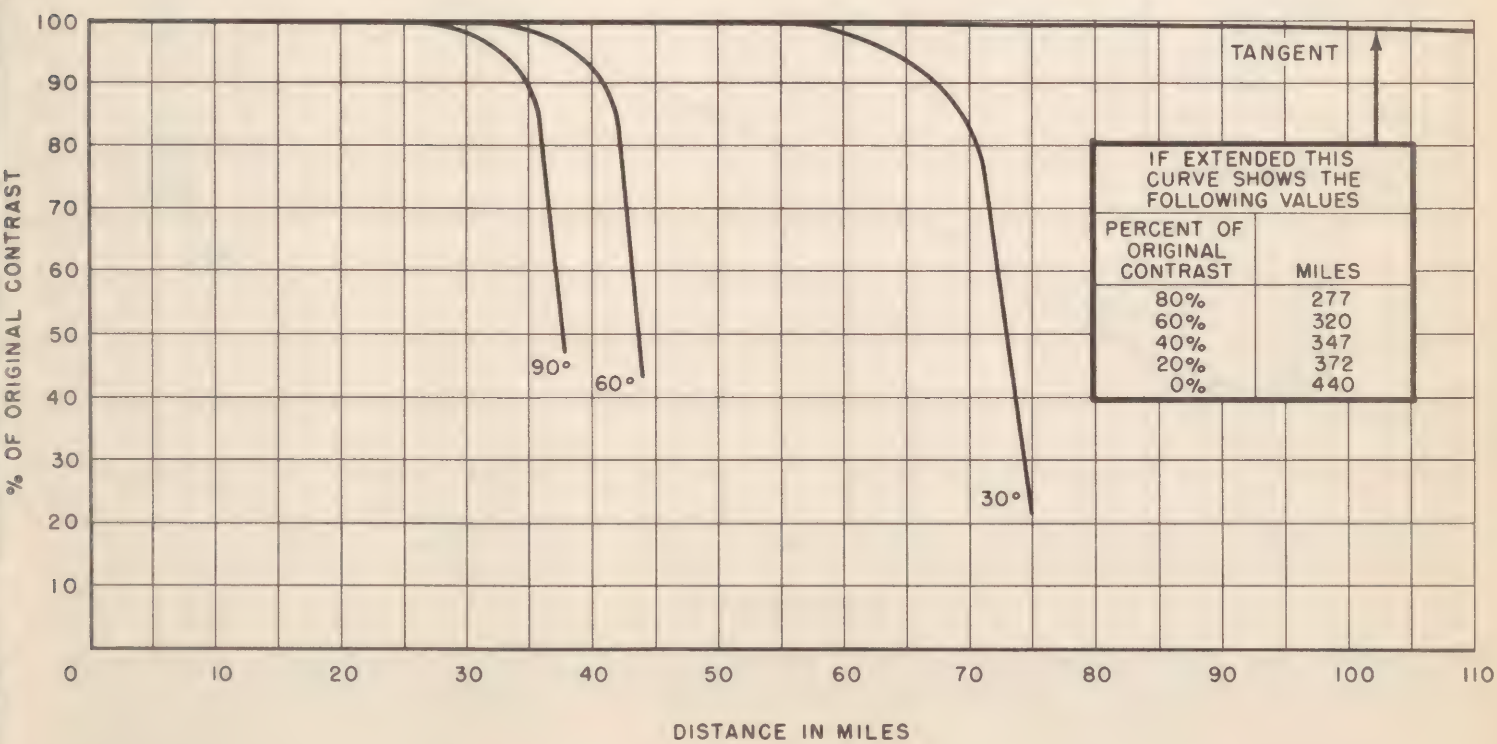

FIGURE 4: THE ATTENUATION OF CONTRAST BY THE ATMOSPHERE ALONG VARIOUS LINES OF SIGHT. THE OBSERVER IS AT 200,000 FEET ALTITUDE AND THE LINES OF SIGHT ARE GIVEN WITH THE EARTH AS A BASE.

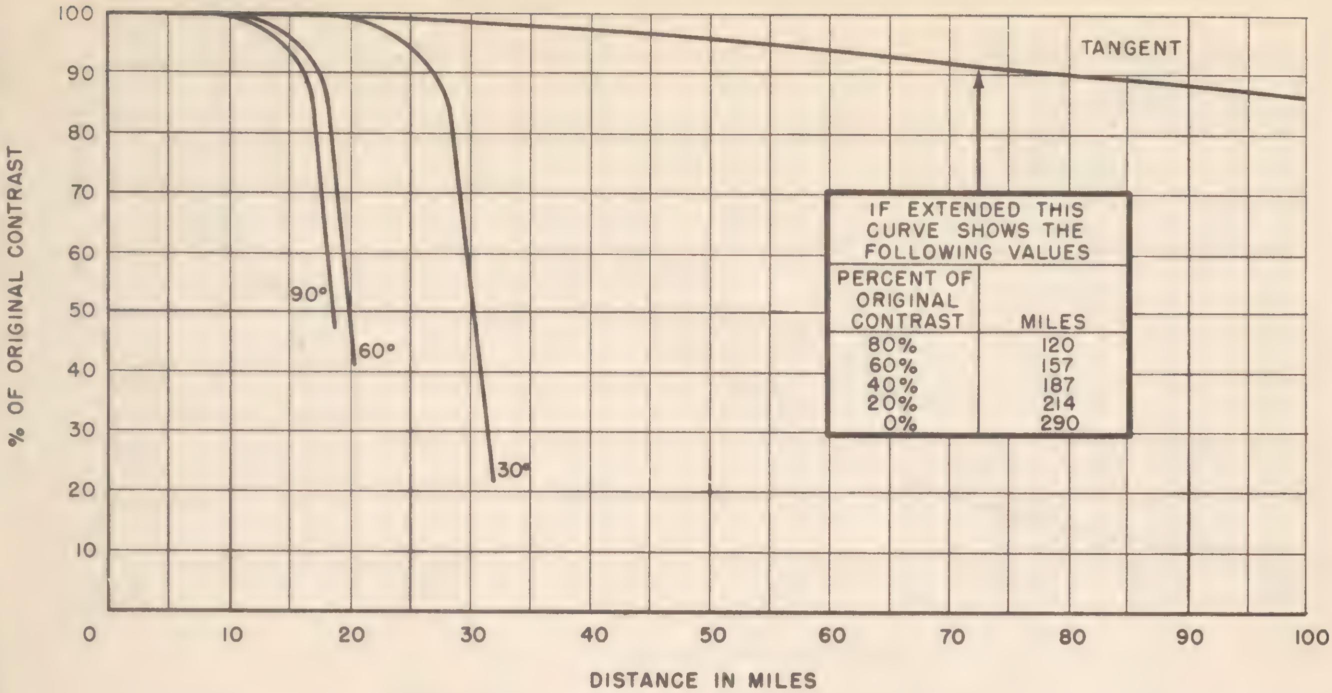

FIGURE 5: THE ATTENUATION OF CONTRAST BY THE ATMOSPHERE ALONG VARIOUS LINES OF SIGHT. THE OBSERVER IS AT 100,000 FEET ALTITUDE AND THE LINES OF SIGHT ARE GIVEN WITH THE EARTH AS A BASE.

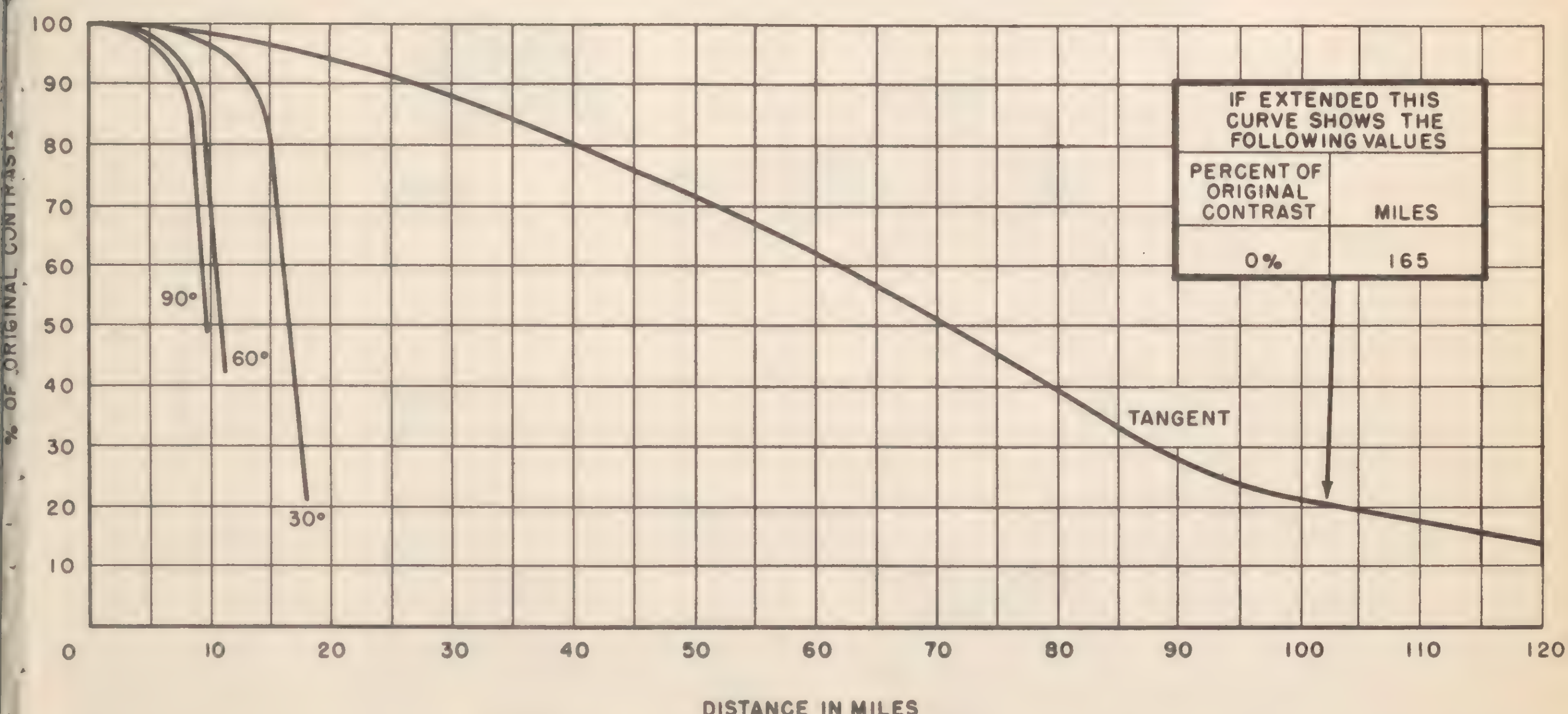

FIGURE 6: THE ATTENUATION OF CONTRAST BY THE ATMOSPHERE ALONG VARIOUS LINES OF SIGHT. THE OBSERVER IS AT 50,000 FEET ALTITUDE AND THE LINES OF SIGHT ARE GIVEN WITH THE EARTH AS A BASE.

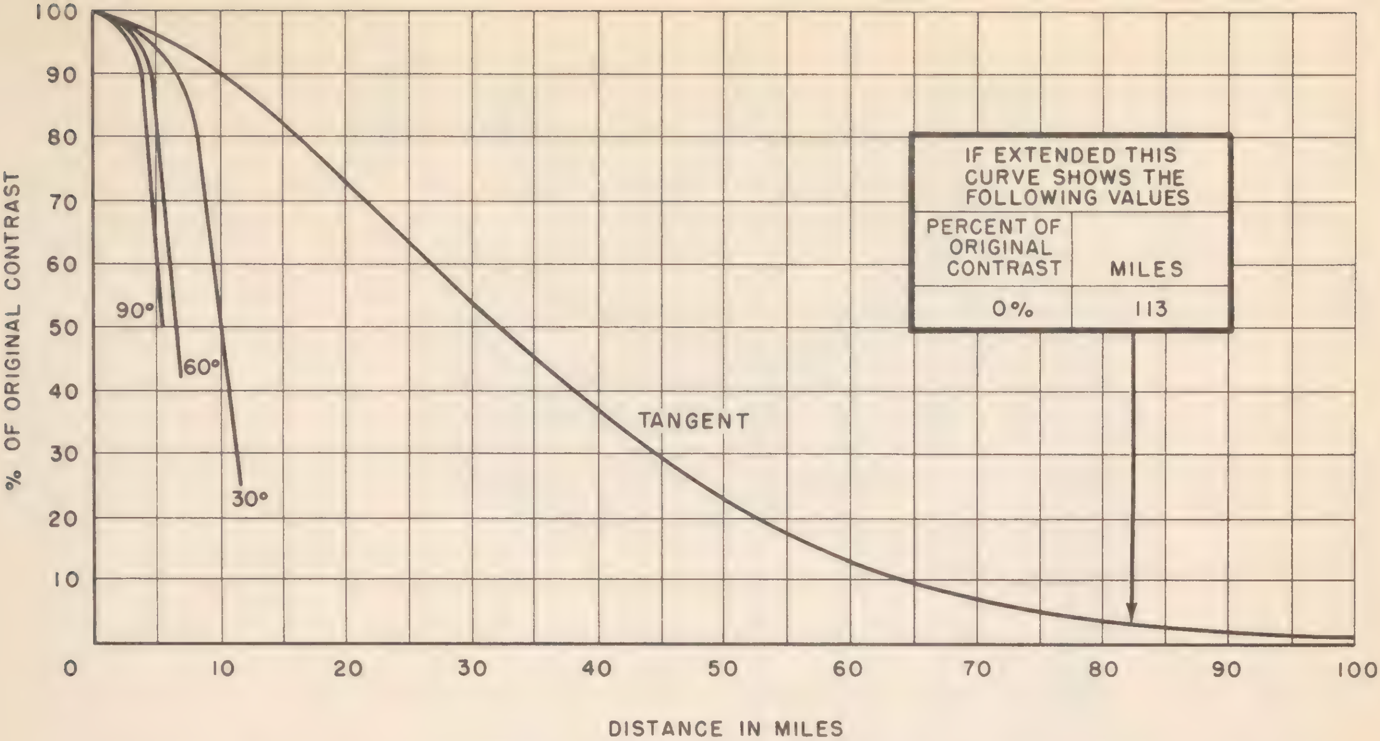

FIGURE 7: THE ATTENUATION OF CONTRAST BY THE ATMOSPHERE ALONG VARIOUS LINES OF SIGHT. THE OBSERVER IS AT 30,000 FEET ALTITUDE AND THE LINES OF SIGHT ARE GIVEN WITH THE EARTH AS A BASE.

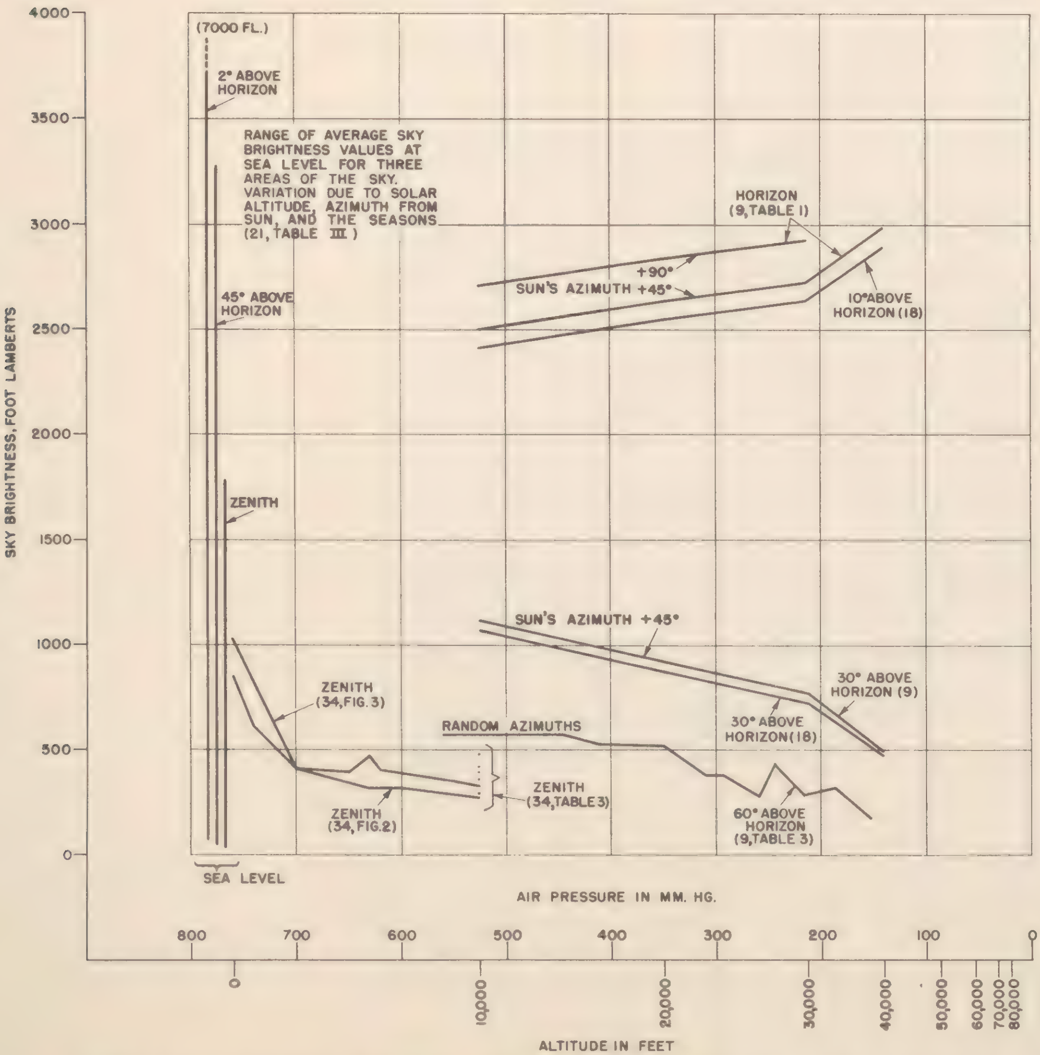

FIGURE 8: RELATION BETWEEN SKY BRIGHTNESS AND ALTITUDE, FOR SEVERAL POSITIONS IN THE SKY. THE NUMBERS IN PARENTHESES IDENTIFY THE STUDIES AS LISTED IN THE REFERENCES AT THE END OF THIS PAPER.

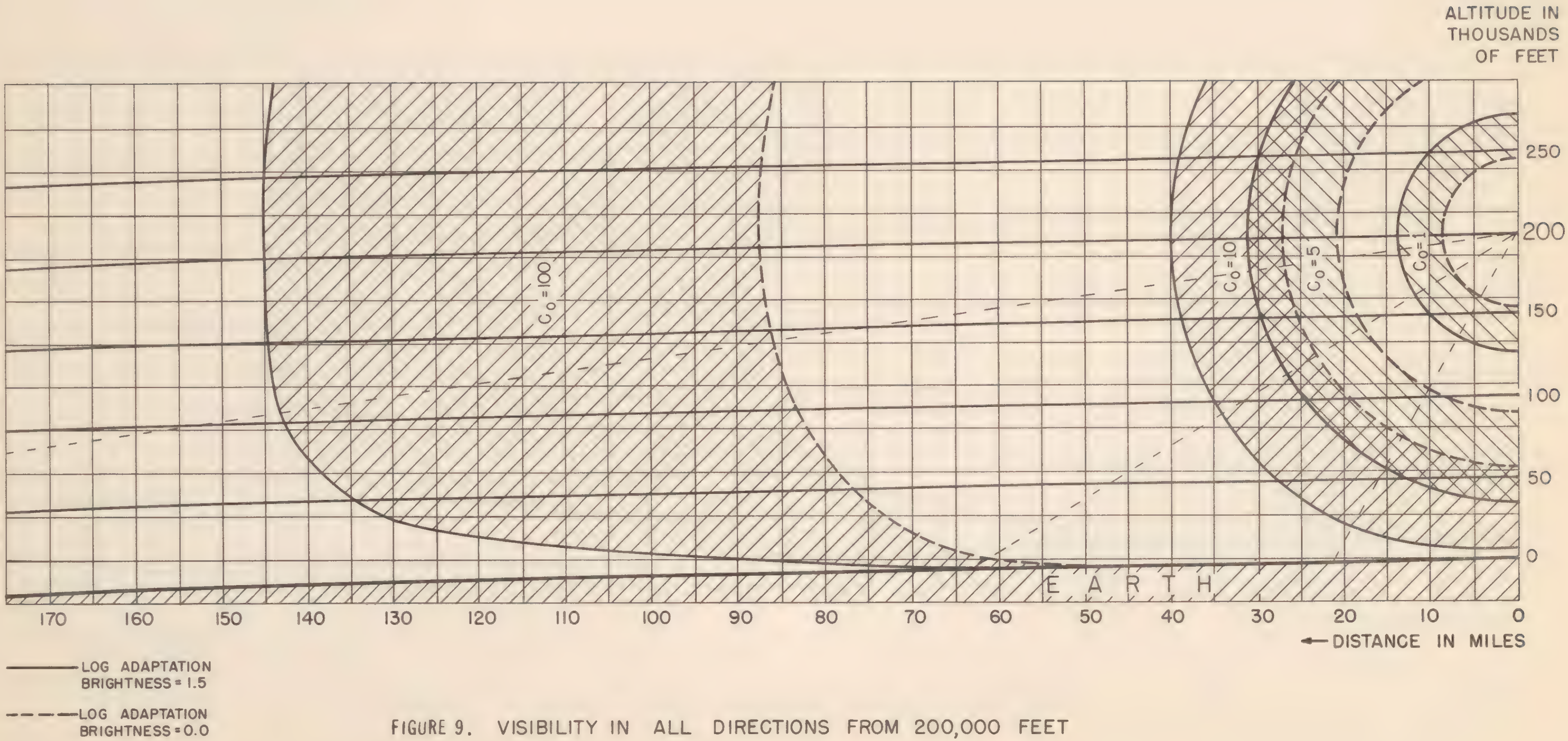

FIGURE 9. VISIBILITY IN ALL DIRECTIONS FROM 200,000 FEET

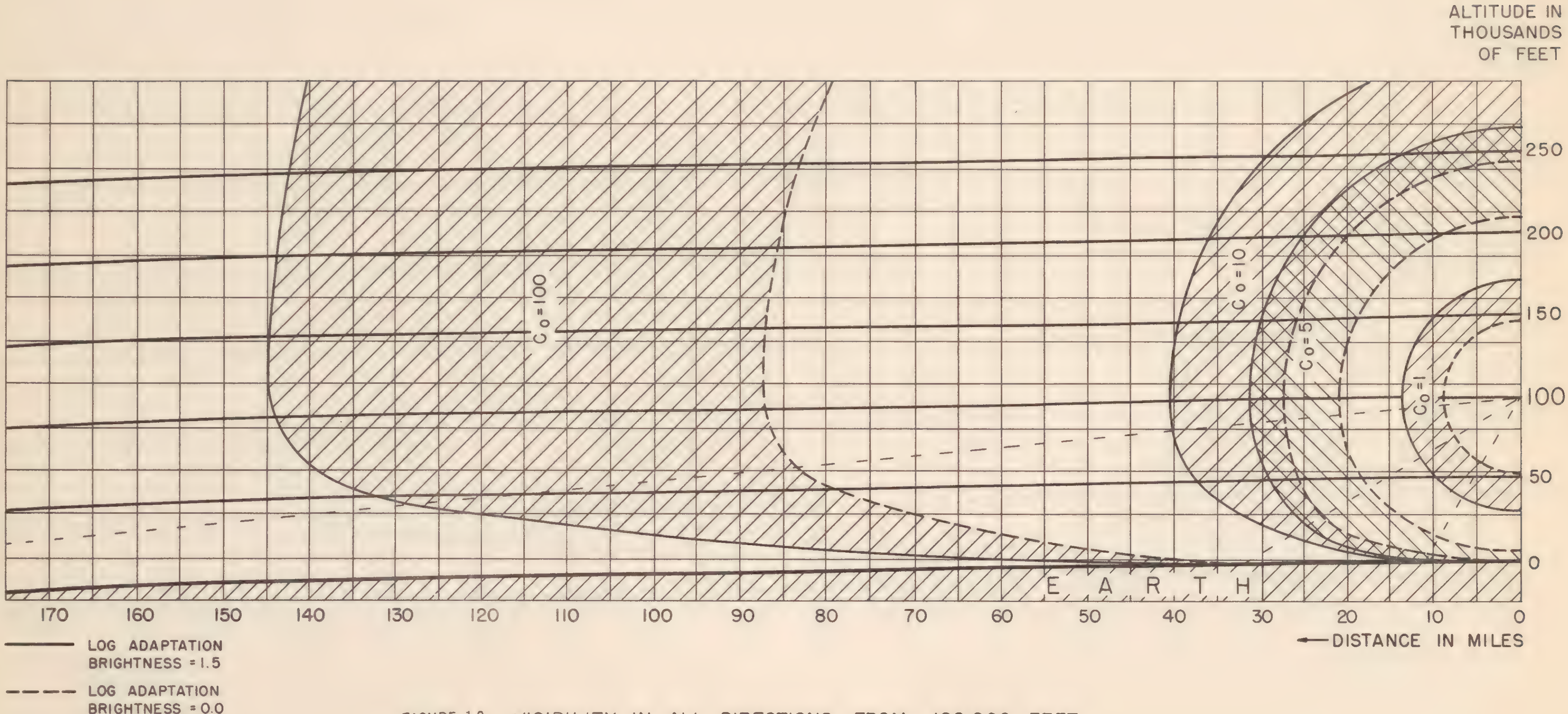

FIGURE 10. VISIBILITY IN ALL DIRECTIONS FROM 100,000 FEET

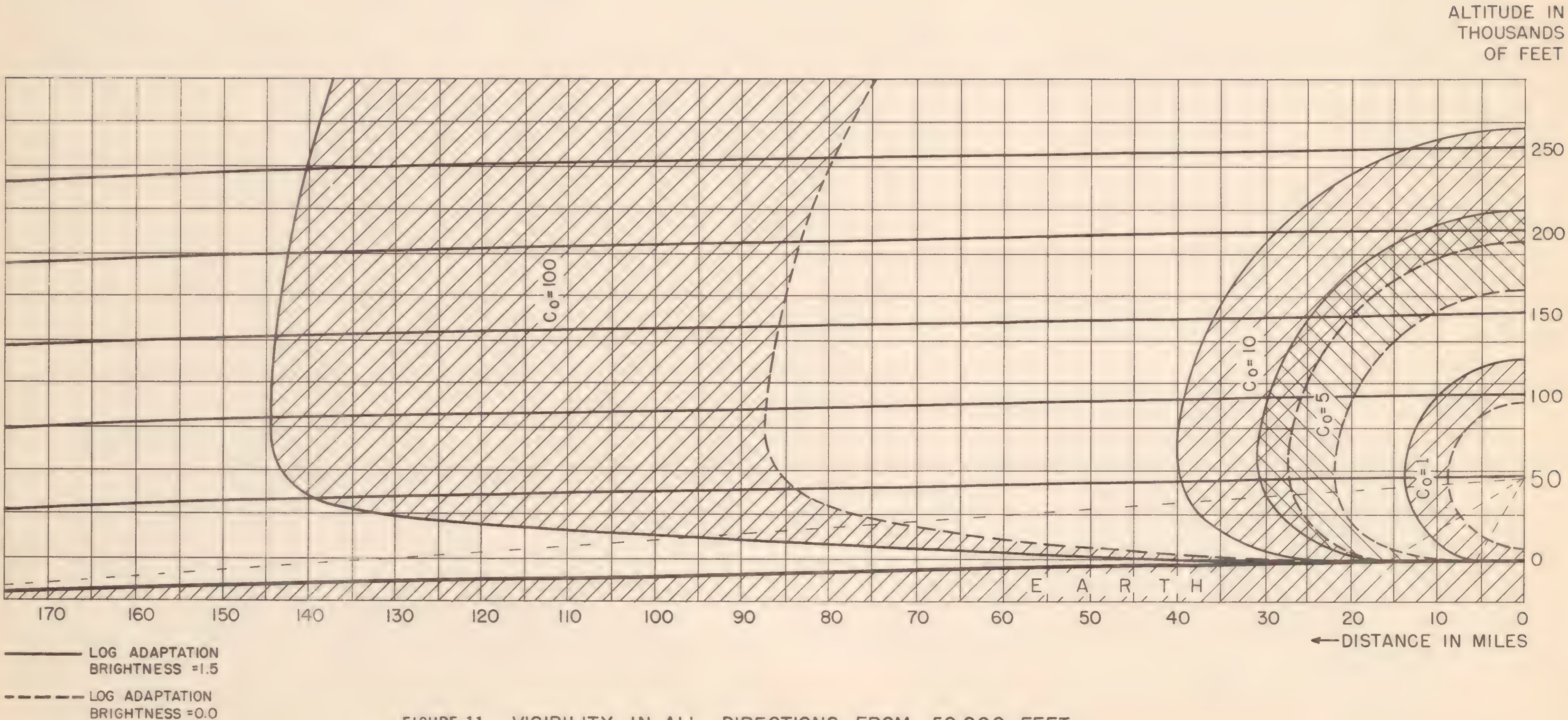

FIGURE 11. VISIBILITY IN ALL DIRECTIONS FROM 50,000 FEET

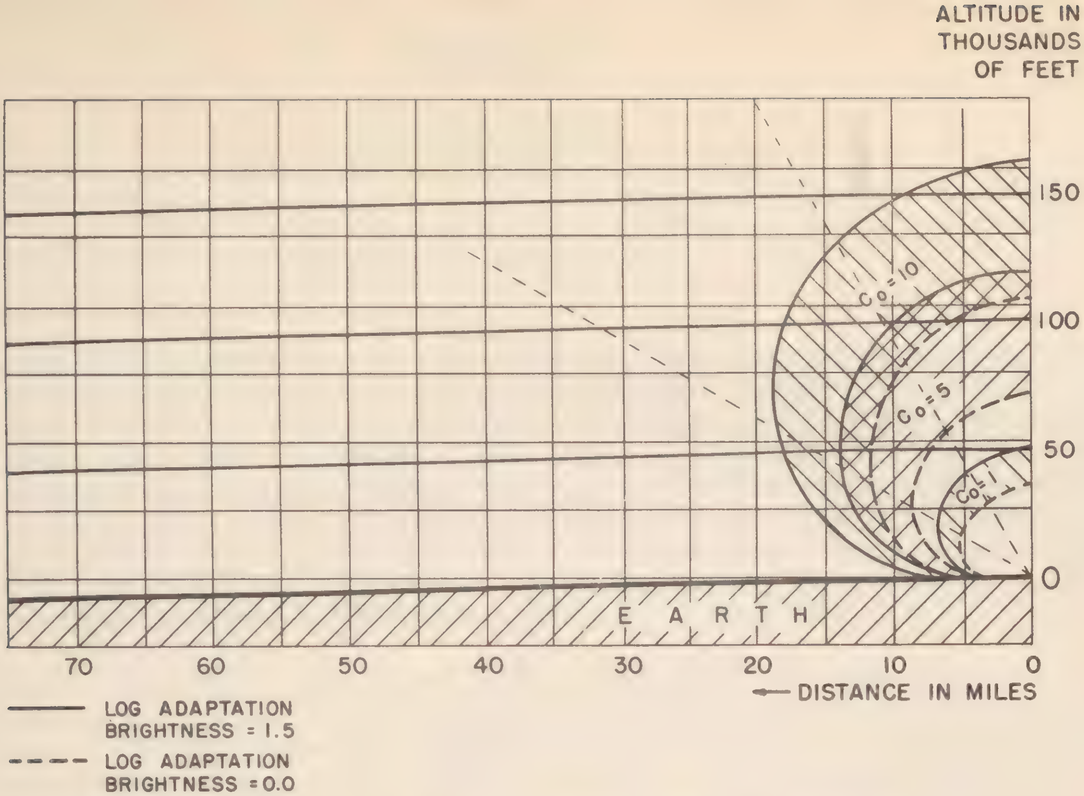

FIGURE 12. VISIBILITY IN ALL DIRECTIONS FROM THE EARTH

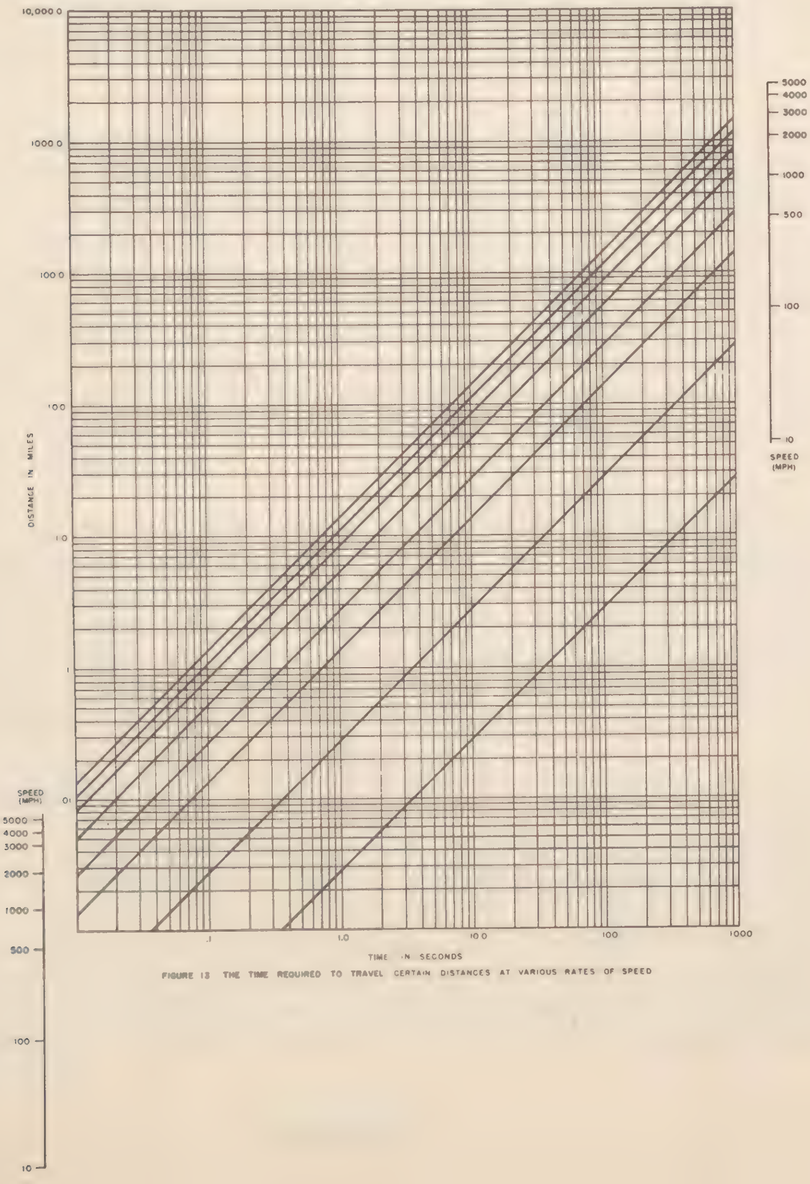

FIGURE 13 THE TIME REQUIRED TO TRAVEL CERTAIN DISTANCES AT VARIOUS RATES OF SPEED

FURTHER RESULTS
FIELD TESTS OF OPTICAL INSTRUMENTS

by
W. S. Verplanck & C. K. Bishop
Indiana University

The project on which the present report is made was set up with the intention of exploiting to the fullest degree possible the data which were collected in the field tests of binoculars conducted at New London during the fall of 1945. The basic analysis of the data provided answers to the problems specifically set for the experiment; that is, it yielded unequivocal results on the relative performance of binoculars in the field. The data, however, had been collected at no little expense of time and effort, and it was evident at the time that the final report was turned in that further valuable information might be extracted from the data if it were further analyzed.

The two most urgent and general problems on which the data might be expected to shed light were the establishing of procedures for the selection of personnel for night visual performance and the validity of proposed methods for the prediction of visibility ranges. A third problem which necessarily had to be considered was the re-evaluation of the original findings on the binoculars themselves, if further analysis suggested contradictory findings. ONR Project N6ori-180, T. O. III was set up at Indiana University with the job of attempting to provide information on these problems by the use of the field data.

The experiment in which the data had been collected may be briefly summarized: the observers stationed on a destroyer escort, approached a group of distant targets, of known size and contrast, and, using the instruments to be tested, yielded to records of the ranges at which each target could first be glimpsed, then seen continuously, and finally identified. Observations were mady by teams of six men on the signal bridge of the vessel, and other three-man teams on the number two gun deck and the lower deck. Rotation of the instruments among the men from target to target statistically controlled variability conditions of each run. The results, the bulk of which were obtained on moonless nights, compared the performance of each instrument with that of the standard 7x50x7 binocular.

The data to be treated, then, were extraordinarily complex. Although thousands of ranges were reported, the fact that different observers made three kinds of reports, of different targets, with different binoculars, under differing visibility conditions, ensured that there was available no large body of homogenous data to treat. The first steps of the analysis to be undertaken, then, were designed to make possible the direct comparison of performances by introducing corrections for many of the variables.

ARGUMENT OF THE ANALYSIS*

The procedure employed made use of the Tiffany Foundation data** to provide new measures of performance. Let us consider a given item of data:

John Jones sighted, at the 100% criterion, a target 6' x 6' square, of contrast 0.95, at a range of 2200 yards, using the 8x60x9^{o} binocular. This binocular magnified 8 diameters, had a light transmission of 0.65, an exit pupil of 7.5 mm., and a contrast rendition of 92. The sighting was made at

night, with a sky brightness of 5.05 log μμL.

The Tiffany Foundation size-contrast data enable us to predict, for a given sky brightness (and adaptation level) the threshold contrast of targets of various retinal subtenses. It is apparent that, since we know 'r', the range, 'S', the target size, 'M', the magnification of the optical instrument, light transmission of the binoculars, exit pupil diameter, and contrast rendition, we may compute the size of the retinal image at the time Jones made his sighting, and that we may then determine, assuming that the Tiffany data are valid, and that Jones is an average observer, the contrast of the target at the time of sighting. The data now available to us for a given contact are 'r', the range of sighting, 'Co', the contrast of the target, and 'Cx', the contrast of the target at the range of sighting. These values are, moreover, independent of the binocular with which the sighting was made.

The assumption of the validity of the Tiffany Foundation data, then, permits us to reduce the number of variables associated with a given sighting to two: the range at which the sighting was made and C_x, the target contrast at which the sighting was made. The observers have, in sighting a target, given a measure of its contrast since, if the observers are reliable, they report a target as soon as its apparent contrast is greater than the threshold value of contrast for a target of such a size.

This contrast measure differs from measures of contrast obtained with such photometric instruments, as the MacBeth illuminometer, principally in the poor conditions (i.e., number of uncontrolled variables effective) under which it was made. In both cases, the measure obtained depends upon the ability of an observer to just make, or to just fail to make, a discrimination. If all the observers were consistent with one another, and if each gives highly reproducible measures from observation to observation, no problems would arise in the interpretation of the field measures obtained. But the observers presumably differ from one another to an unknown degree and vary from time to time in their sensitivity or efficiency. Further, in the sighting situation, it might be expected that variations in contrast of the target as 'measured' at any given range will appear which are the consequence of variations in the transparency of the air, as measured by β, the coefficient of atmospheric attenuation.

Let us suppose, for the time, however, that all observations are made under identical conditions, and that β does not vary,-- i.e., that there is a "right" target contrast for a given range. Now, if all the observers are equivalent, and show low variability, the measures of C_x obtained will not show great variability, and may be employed in the familiar relationship:

$$C_x = C_o e^{-\beta x}$$

to compute the value of β, the coefficient of atmospheric attentuation, at the time of sighting. When differences in the value of C_x now appear, they may be attributed to (a) differences in the mean sensitivities of each observer,

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*Since, at the time of presentation, it was evident that a fuller explanation was required, the published form of this section is somewhat expanded.

**Blackwell, H. R. Contrast thresholds of the human eye. J. Opt. Soc. Amer. 36 624 (1946)

and to (b) the variability of each observer in sensitivity to contrast.

An equivalent situation would pertain if we had, instead of a number of observers, a number of physical instruments, all designed to measure contrast, and all equally "valid" in design for the measurement of contrast, -- but all yielding different values of β, and with different errors of measurement.* To obtain a measure of β, we would then necessarily -- when there is no evidence with respect to optical or other physical errors in the measuring device -- have to use the mean value of β, computed for observations made with all instruments. From this, we would very likely compute a constant error for each instrument, and a variable error for each one as well. Analysis of such results might show any of three effects: (a) that all instruments give, on the average, the same measurement, and all variability is due to variable errors of measurement; (b) that each instrument gives a precise measure (i.e., has a small variable error), but that each shows a different constant error; or finally (c) that each instrument has its own characteristic values of both constant and variable errors.

The problem is that of individual differences, and it is the first with which we shall be concerned in analyzing the present data; are all our subjects equivalent with respect to the measures of β which may be computed for the values of C_x which they yield?

Now let us make a different assumption. Let us suppose that our measurements are made on several different occasions, and that the value of β,** as obtained by a completely valid and reliable "physical" measurement is allowed to vary, i.e., that the measurements are made under various conditions of visibility. Pursuing the analogy we have proposed, it is obvious that if we were dealing with photometric measurements, we would still have to evaluate β for each occasion on which measurements are made from the mean reading of all the instruments. This error of measurement of this value will depend upon both the constant and variable errors of our instruments. As sampling error is reduced by increasing the number of instruments and the number of readings made with each, the accuracy of the mean values obtained is increased.

If we assume the validity of the Tiffany Foundation data, then it follows that we may evaluate β from the values of C_x obtained on any one date, provided that proper statistical precautions, which will be indicated in the proper place, are taken.

The argument, then, rests on the assumption of the validity of the Tiffany Foundation data for the prediction of observing behavior in the field. The same procedure may be applied to this problem which holds for the validation of

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* Such discrepancies among measurements obtained with different physical instruments employed in the measurement of β are by no means unheard of: see Blackwell, H. R., this issue, this publication.

** Mathematically, of course, β is a constant. However, it is treated as a variable usually dependent on such meteorological variables as the dispersion of aerosols in the atmosphere, etc. since it assumes different values as such variables alter. To vary the value of β systematically, means to select data from occasions on which β differed, then to treat β as an independent variable, and to treat together the data obtained on each of such occasions.

the photometric instruments in our analogy. The mean values of β should vary from night to night, but should not vary greatly with any one night. The values of β obtained, then, must meet certain criteria established by common sense and by unaided observation: (1) a minimal number of values of β may be 0.00 or less; (2) a minimal number of values of β may exceed 1.50, the value of β corresponding to visibility conditions under which measurements could not be made; (3) the distribution of values of β must correspond with the distribution of visibility conditions correlated with them, and observed during the time measurements were made; (4) the values of β obtained must be employable to predict the range at which targets are sighted, when the measures of β are obtained quite independently of these sightings.

It is this argument on which the statistical analysis of our data rests. From the empirical values of x, the range of sighting, C_o, the target contrast at 0 range, and of C_x, the measure of target contrast at range X (apparent contrast), which is obtained by computation from X, the sighting range, from the optical characteristics of the instrument with which sightings were made, and by use of the size-contrast data of the Tiffany Foundation, we have converted each sighting range into a value of β, and have separately examined (a) the variability of observers in the values of β obtained, and (b) the validity of the observers as instruments for the measurement of β. For each part of the analysis, separate problems arise, the solutions of which will be presented as the occasion arises.

TREATMENT OF THE DATA

In preparing the data for analysis, the first step was the computation of tables for the conversion into values of β, each range of sighting. One such table had to be prepared for each binocular, and for each target and criterion of seeing. In the preparation of these tables, the following variables were taken into account: (a) target size, (b) target contrast, (c) magnification of the instrument, and (d) contrast rendition of the instrument. Three variables, which could have been included in the determination of these β values were not incorporated, since a series of trial computations showed that their effect on the values of β computed was small, and that, if they were incorporated, the additional computational labor required was enormous. They may all be taken into account later, if it proves necessary.

These temporarily neglected variables were sky brightness, and the light transmission and exit pupil of the binocular. All three might play a role in the selection of the particular curve of the Tiffany Foundation employed, but the following considerations pertain: (a) sky brightness did not vary considerably throughout the experiment for the value 5.05 log μμL; (b) the light transmission of the binoculars did not vary considerably from instrument to instrument. If densities are computed, the average density of the binoculars was .10 log units; (c) exit pupil diameter could not be treated in, since effective exit pupils depend on the dark-adapted pupil diameters of the observers, whose mean value was 6.9 mm., with a standard deviation of 1.0 mm. Thus, for half the observers, exit pupils greater than 7.0 mm. might prove of some advantage, but for the other half, the limiting factor is not the exit pupil of the instrument, but the entrance pupil of the observer. Most of the instruments studied had a 7.0 mm. exit pupil, and of the instruments used to any great extent, only the 10x50x7 should exit pupil consistently play a major role. Sky brightness, light transmissions, and exit pupils were therefore considered together, and the 5.00 log μμL curve of the Tiffany data was employed

in preparing the tables. The error introduced by this approximation did not exceed a very few percent in the values of β obtained.

The values of β computed we have termed β_z, since the brightness variables have not been considered, and since such variables as cloud coverage and wind may also have affected sighting ranges. The values of β_z obtained were coded, and placed on IBM cards together with other pertinent data, for statistical analysis. This statistical analysis was performed on the largest sets of homogeneous data available.*

INDIVIDUAL DIFFERENCES

The first results to be reported are those on individual differences in performance. The first effort in this direction was to evaluate the mean values on each night of β_z for all the observations made on the signal bridge, and on the gun deck for all observers, and for the observations of each subject separately. From these were computed the differences between the observer's means, and the appropriate group means. If significant differences in performance among observers exist, we should expect to find that superior observers consistently (from night to night) give negative values of the mean differences, and the poor observers positive values. The index of observer performance obtained in this way for each night is termed $\bar{P}$.

Table I gives the mean and S.D. of the values of $\bar{P}$ obtained on all 39 observers who served four or more nights, together with the values of the F and Σ^2 tests of significance of differences. The values obtained indicate that there are significant differences among observers, but that the differences are small among the majority of observers. A glance at the mean values of $\bar{P}$ confirms this; the distribution $\bar{P}$ is leptokurtic ($2_4 = 6.61$).

A second procedure was also employed for the establishment of individual differences in performance. This method similarly compared the performance of individual observers with the mean performance of several observers, but the second procedure employed as the standard of performance, not the mean value of β_z obtained for each night, but the mean value of β_c, which is the best estimate of β, the coefficient of atmospheric attenuation, which could be obtained for each run. The procedure whereby this value was computed will be presented later in this report. This second estimate gives a difference value, $\bar{p}$, for each observer on each run, for each binocular and target. Table II gives the value of Σ^2 testing the reliability of differences among observers in the values of $\bar{p}$. Again, the differences are slight, and do not lend themselves to useful prediction of performances, but they are reliable.

Since $\bar{p}$ has been evaluated for each subject on each of several instruments and targets, we should expect, if our subjects are consistently different from one another, to be able to predict their performance on one target from

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* The data on the following classes of data, not homogeneous with the remainder were generally excluded from full analysis for the reasons given: (a) Daylight runs: insufficient data, (b) search data: insufficient data, (c) Runs at 17 knots: insufficient data, (d) Data collected at position 6, signal bridge: shown in Field Tests of Optical Instruments to yield data significantly different from other posts, and (e) Glimpse and Positive Indentification data: the original analysis showed that these data differed significantly from those for "100% seeing," which proved to be most comparable to the threshold measures of the laboratory.

their performance on another and also, if there is no significant interaction between subject and binocular, from one binocular to another binocular. Rank order correlations were therefore run between $\bar{p}$'s obtained by the various observers on various binoculars and targets, and only one significant ρ was found: a value of .591 (7x50x7 HH, S.B., targets 3-100 vs. 4-100). It should be noted that the 7x50x7 HH, S.B., target 3-100, is the performance on which the most significant differences were found between observers (Table III). This result is to be expected if individual differences are small and unreliable.

We have also attempted to relate the index of performance obtained in mean values of $\bar{p}$ with the various selective tests which were employed. These were: (a) the absolute terminal threshold (RCN), (b) average dark-adaptated pupil diameter. (c) R.P.A. performance, (d) presence of phoria (Orthorater), (e) visual training, (f) experience in observation, and (g) basic experience or training prior to participation in the experiment. Mean $\bar{p}$ was also correlated with mean values of $\bar{P}$. Table IV gives the correlations obtained. It is evident that no significant correlations are present except the spurious one between $\bar{p}$ and $\bar{P}$, which is inevitable from the fact that both were computed from the same data.

The relationship between the subject's rating of the various instruments, and the values of $\bar{p}$ obtained with them was examined. Fifty-six such Pearson product-moment correlations were computed. Only five of these were significant between the 1 and 5% levels of statistical significance. The probability that five such "r"'s should appear in a population of fifty-six coefficients and correlation in the absence of any significant relationship is relatively large: 16/100.

Finally, an attempt was made to determine whether any significant evidence for subject-binocular interaction could be adduced. To date, no such relationship has been discovered, beyond that stated in the original report, <u>Field Tests of Optical Instruments</u> (Navord 77-46).

This consistently weakly positive evidence is what might be expected if there were few or no important significant differences among the observers. We have, consequently, examined the data further and have made some rather interesting findings.

First, there was earlier reported, in Navord 77-46 considerable evidence for the existence of reliable individual differences; the present evidence does not support this very convincingly. It is suggested, as a tentative hypothesis, to be tested by further analysis of the present data, that the variability of the individual's performance is not random, but systematic, with the individual's performance relatively stable over short periods of time, but varying systematically over long periods of time about a mean value. Such an hypothesis would account for the instability of individual differences when they are erratically sampled over a long period (as in the present experiment), and their stability when sampled over a short period. A further implication is that, if samples of performance are evenly drawn over a long period of time from the members of a population, significant individual differences might again appear.

Second, an examination of the mean values of $\bar{p}$ and $\bar{P}$ shows that two observers, each at one of the tails of the distribution, seem to differ widely

from the other observers in performance. Indeed, if these two observers are dropped from the population, all evidence for stable individual difference disappears. Of a population of 39 observers under consideration, 32 were naval enlisted men, and were not selected for the purposes of the experiment.* Most had passed the physical requirements for the submarine service at one time, but were not re-examined at or near the time of the experiment. The remaining 7 observers were all scientific personnel: physicists, physiologists and psychologists, who were considered to be especially well-qualified as observers. The two extreme observers are both from this group.

Further statistical analysis, aimed at clarifying the results with respect to these findings, is being undertaken, and the results will be incorporated in the project's terminal report. No final conclusions may be put forth until this work is complete, but to date the data seem to suggest that, among members of a service population, there do not exist any substantial stable long range individual differences in visual performance, although on any one night, one observer may perform consistently and considerably better than another. As a corollary, it would seem to follow that efforts to select naval personnel for lookout or other free visual observational duty will prove unproductive. Further, it would appear that training and experience beyond one or two sessions, either as a practice lookout, or in a lookout school do not contribute to improve performance, since all our observers shared this minimal experience before observing.

ESTIMATION OF β, AND EVALUATION OF THE VALIDITY OF THE TIFFANY DATA, AND OF THE NOMOGRAPHS BASED UPON THEM

In an earlier section of this report, it was indicated that failure to take into account four variables which are not associated with the variability of the individual observer, sky brightness, light transmission of the binocular, cloud coverage, and wind blowing in the observer's face, immediately barred the use of the quantity β_x as an estimate of β, the coefficient of atmospheric attenuation, prevailing on any given night of observation.

A statistical technique was employed which permitted the partialing-out of three of these extraneous variables, so that a corrected value of β could be computed from the values of β_z obtained from the ranges. For most nights of operation, several items of pertinent data were available. Cloud coverage had been estimated by the quartermasters. Wind force had been evaluated on the Beaufort scale, again by quartermasters, and the sky brightness had been measured by the O'Brien low-level illuminometer. In the earliest studies, visibility (in miles), as evaluated by the quartermasters was also included. Correlations were run among these measures; multiple regression equations were derived; and new values of β, termed β_c, were obtained for each run, on each of several binoculars and targets. This analysis was restricted to those binoculars and targets on which there were available the largest sets of data. It was not considered advisable to use instruments which had been used only once or twice on any one night or targets which were not regularly sighted. Data from the signal bridge, and from the two courses on the gun deck were kept separated, since reliable differences have been shown between observations made under these three conditions, and it appeared probable that the analysis might reveal the sources of this difference.

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* This is true of all the observers who participated. None had to be disqualified for visual reasons.

The first examination of the coefficients of the regression equations revealed that wind, and secondarily, sky brightness, were more important as contaminating factors in the data obtained on the gun deck, than in the data of the signal bridge. This strongly suggests that these factors may have played a critical role in yielding the short sighting ranges which characterized the results obtained on the gun deck. In the analysis we have, therefor, kept the data from these two observation positions separate, and we have further kept separated the gun deck data on the two courses, which showed statistically significant difference.

If the quartermaster's visibility estimates were valid, the values of β_c obtained throughout the experiment, and with any instrument, should not differ significantly, either within a night, or from night to night. Application of the F test for significance of differences should show significant differences from night to night in the values of β_c, but should show only chance differences within the observations of any night. If the estimates of visibility were consistently too invariable (visibility over-estimated when poor, and under-estimated when good), this is exactly what we would expect to find. We should find, too, low and unreliable positive correlations between β_z and visibility. These results were obtained. The terms correcting for quartermaster's estimates of "visibility" in the regression equations were almost invariably small, and did not contribute importantly to the values of β_c. Σ^2 analysis between mean β_c values of all the instruments used on a particular run on a given night, and the mean β_c obtained on all the runs and on all instruments used on a night were performed. The data obtained on all targets at the 100% criterion of seeing were used and were computed separately. Of the 132 Σ^2's for significance of difference among runs of a night which were computed, only eight were significant at the 5% level, and only one at the 1% level. This number is close to chance expectancy.

Statistically significant differences were found, on the other hand, among nights in the data on each of the most frequently employed instruments* (Table V). The first criterion proposed for the validation of the Tiffany data seems to have been met.

It has been stated that the mean values of β were obtained from run to run or from night to night should be distributed in a certain way: no value less than 0.00 should appear, and no values greater than 1.50, corresponding to a visual range of 2-3 miles, which was the minimum under which the tests were conducted, should appear. Finally, the average value of β should correspond with an average "clear" daylight visual range. Table VI gives the average values of β_c, for the 7x50x7 binocular (on which most data were available), for each of two targets. Although the values obtained with the two instruments differ, the correlation between them is high, and the distribution of visibility values obtained is in excellent agreement with what must be expected. By way of further evidence, it should be pointed out that Dec. 9 is the final date of the experiment, a night on which the visibility was sufficiently poor that no data at all were obtained on several instruments. β_c's obtained with all of the instruments met this criterion, with the exception of the 20x120x3.6, which gave a few maximum values of β falling beyond the 2-3 sea mile lower visibility limit; this result is to be expected from an instrument of very high magnification, since all the experimental data available show

* We are restricted to these instruments since they are the only ones used on enough nights to ensure a sampling of the various visibility conditions encountered.

diminishing ranges with higher magnification.

The second criterion for the validity of the Tiffany data is met.

The third criterion which our estimate of β should meet in order to evaluate the Tiffany data is the demonstration of their usefulness in predicting the ranges at which a target may be seen with a particular set of binoculars. A method is available which is perhaps especially useful since it makes direct use of the nomographs derived from the Tiffany data. This method was developed by Coleman in Navord Report 438, entitled <u>A Method of Predicting the Range at Which Targets are Detectable through Visual Telescopic Systems</u>. In this report, Coleman makes use of the data employed in this report, and shows that they are predicted by the visibility nomographs. The present procedure makes use of the same procedure, but employs, instead of the fictitious values of β which Coleman must have employed, the values of β_c which we have obtained on the 7x50x7 binocular, target 3-100, to predict the actual ranges at which the same targets were detected with <u>other</u> binoculars.

The procedure demands that the inherent target area, the inherent target contrast, the brightness against which the target is seen, the meteorological range, and the shape of the target be known. By means of nomographic visibility charts,* it is then possible to read off the detection range of that target.

The estimates of the meteorological range for any operating night employed was mean values of β_c as determined by the 7x50x7 HH on target 3-100. This instrument and target were used, because all previous analyses showed that the data obtained by this instrument and target were the most reliable. Since all the other data required are known, predicted ranges may be readily obtained.

Interest was primarily centered on the amount of error found between the ranges predicted by Coleman's method and the ranges obtained in the Field Test. If the error is small it may be of the same order of magnitude as the error of reading the nomograph charts. Such predictions were accordingly made for all the binoculars and targets for each night.

The results showed that the amount of error was small, ranging from .03 log units to .15 log units. Only two glasses gave exceptionally large errors of prediction. These were the 25x100x3.6 Mtd. and the 20x120x3 Mtd. Here the magnitude of error between predicted and experimentally obtained ranges varied from .18 log units to .30 log units -- an error as great as 100%. Both these instruments, as has been stated before, show the effects of the diminishing returns obtained with high magnifications.

The third criterion seems satisfied. The results on this visibility analysis, which is essentially complete, seem clear: when the validity of the Tiffany Foundation data is assumed, the field data may be converted into measures of β, the coefficient of atmospheric attenuation, which show properties such as would be expected of measures of β obtained by more obviously photometric measures of the constant. It may be concluded, then, that the Tiffany Foundation data may be used to predict accurately the ranges at which targets may be sighted in the field, and also to predict, when taken with

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* Duntley, S. Q., The visibility of distant objects. J. Opt. Soc. Amer. <u>38</u> 237 (1948)

suitable optical measures, the relative ranges obtained in the field by binoculars of various types and of relatively low (less than 12) power.

SUMMARY

(1) The field test data show slight but significant individual differences in visual performance.

(2) The field test data lend support to the view that the Tiffany Foundation data and nomographs based on them, may be employed both to predict the ranges at which specified targets may be sighted when the meteorological range is known, and to predict the relative usefulness of binoculars of various optical characteristics in sighting such targets.

DISCUSSION:

There was considerable discussion concerning day to day variability in night vision performance. Dr. Verplanck expressed his belief that night vision varies little within a short range of time, but varies considerably over a longer range of time.

Professor Hardy expressed a question as to the wisdom of assigning a beta value to explain differences in individual variability. He expressed the belief that the differences between individuals will be constants rather than exponents which are dependent upon distance.

Professor Hardy also stressed the point that the field results do not "test" the Tiffany nomographs, but rather test the experimental procedures used in the field studies.

Dr. Verplanck agreed with Professor Hardy's last point and stated again his conclusion that the field results obtained showed good agreement with the Tiffany nomographs.

Dr. Sheard expressed his belief that one should not expect data obtained in the field to be related in a meaningful fashion to data obtained in the laboratory because of the possibility of many factors in the field which are absent in the laboratory.

Dr. Verplanck agreed that there was a real possibility of many factors in the field which did not exist in the laboratory. He stated that the purpose of comparing field and laboratory data is to evaluate the order of magnitude of effect to be expected from these variables. We are interested in what people will do in the field, and in how much people differ from one another when they are not under carefully controlled conditions. In the New London studies, the attempt was made to control the subjects only as well as they would be controlled under ordinary circumstances in the field. The problem then is to find out to what extent data obtained on the eyes of girl observers in the laboratory predict what a group of sailors will see on a ship at night. The conclusion was that there were no consistent differences between the observers and that laboratory data can be used to predict visual ranges at sea at night quite well.

Captain Shilling agreed with Dr. Verplanck and stated his belief that line officers cannot be expected to believe that data obtained on girls in the laboratory are applicable to sailors at sea. He felt that for this reason, the kind of study conducted at New London was necessary and desirable.

TABLE I

Mean and Standard Deviation of Values of
Mean $\bar{P}$ on the 38 Observers
with more than three sets of observations

Observers	$M\bar{P}$	SD
An	-.05	.41
At	-.11	.40
Ba	.24	.26
Bb	-.13	.23
Br	.07	.53
Ca	-.07	.38
Co	-.03	.34
Cr	.00	.23
Fi	.13	.45
Fo	.22	.53
Ha	-.05	.44
He	-.56	.70
Hu	.36	.49
Ja	-.42	.63
Kl	.06	.33
La	.39	1.17
Lm	.03	.38
Le	.10	.25
Mi	-.18	.54
Mg	.50	.70
Mu	.11	.31
My	.04	.33
Na	.35	.54
Ni	-.08	.26
Pa	-.08	.39
Pe	-.09	.45
Pu	.02	.44
Ri	.00	.21
Rt	-.21	.38
Ro	-.19	.38
Sh	-.04	.33
Sm	-.10	.28
Sk	-.03	.25
Tu	-.16	.34
We	.13	.48
Ws	.33	.49
Wi	.11	.24
Za	.05	.17
Mean	.034	.412
SD =	.243	.179

$\Sigma^2 = .22$

$F = 2.92$

$p = < .01$

TABLE II

Reliability of Differences Among
Observers in Values of $\bar{p}$ as Measured by Σ^2

Instrument & Target - $\bar{p}$	Σ^2	p
7x50x7HH SB 3-100	.222	$<.01$
7x50x7 HH SB 4-100	.073	$>.05$
7x50x7 HH SB 6-100	.166	$>.05$
7x50x7 HH 210° GD 3-100	-.194	$>.05$
7x50x7 HH 065° GD 3-100	-.080	$>.05$
7x50x10 HH SB 3-100	.724	$<.01$
7x50x10 HH SB 6-100	.550	$.05 > p > .01$
10x50x7 HH SB 4-100	.211	$<.05$
20x120x3 Mtd. SB 6-100	.844	$<.01$

TABLE III

Rho's, N's, and p between mean $\bar{p}$ of Observers

on One Binocular and Target, and

Another Binocular and Target

	7x50x7 HH SB 4-100	7x50x7 HH SB 6-100	20x120x3 Mtd SB 6-100	7x50x7 065° GD 3-100	7x50x7 210° GD 3-100	10x50x7 4-100	7x50x10 3-100	7x50x10 6-100
	N ρ p	N ρ p	N ρ p	N ρ p	N ρ p	N ρ p	N ρ p	N ρ p
7x50x7 HH SB 3-100	49 .591 p>.01	46 .273 NS	24 .216 NS	8 .214 NS	8 .000 NS	15 .064 NS	12 -.168 NS	-
7x50x7 HH SB 4-100	-	44 .197 NS	-	-	-	30 .278 NS	-	-
7x50x7 HH SB 6-100	-	-	24-.034 NS	-	-	-	-	15 .361 NS
20x120x3 Mtd SB 6-100	-	-	-	-	-	-	-	5-.800 NS
7x50x7 HH 210° GD 3-100	-	-	-	8 .214 NS	-	-	-	-

TABLE IV

Measures of Correlation Among Predictive
Tests and Measures of Performance

	Mean $\bar{P}$	p	Mean $\bar{p}$	p
Absolute Terminal Threshold (Pearson's r)	-.063	$>.05$	-.329*	$.05>p>.01$
Ave. Pupil Diameter (Pearson's r)	-.195	$>.05$	.100	$>.05$
R.P.A. (biserial r)	.291	$>.05$	.109	$>.05$
Esophoria Exophoria (biserial r)	.003	$>.05$	.255	$>.05$
Lookout School (biserial r)	.080	$>.05$	.052	$>.05$
Lookout or QM, SM, Watch (biserial r)	.052	$>.05$	.103	$>.05$
No School or Watch (biserial r)	.138	$>.05$	.199	$>.05$
$\bar{p}$ (Pearson's r)	.493	$<.01$		

* This correlation is in the direction opposite to that predicted on the basis of the "face" validity of the absolute terminal threshold for prediction of visual performance at low levels of illumination.

TABLE V

Probabilities of statistically significant differences among nights in mean values of β_c, based on Σ^2 analysis

Signal Bridge Sightings
Target 3-100

Instrument	Target	P
7x50x7 HH	3-100	P <.01
7x50x10 HH	3-100	.05 > P >.01
10x50x7 HH	3-100	P <.01
20x120x3.6Mtd.	3-100	.05 > P >.01

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TABLE VI

Mean Values of β_c
on Each Operating Night, Together with
the Corresponding Daylight Visual Range (D.V.R.)
Computed from Data on Each of Two Targets

Date	7x50x7 SB 3-100 β_c	7x50x7 SB 3-100 Corresponding DVR (Sea Miles)	7x50x7 SB 4-100 β_c	7x50x7 SB 4-100 Corresponding DVR (Sea Miles)
September 5	.387	10-11	.608	6-7
September 6	.506	7-8	.549	7-8
September 7	.535	7-8	.548	7-8
September 12	.568	6-7	.582	6-7
September 13	.792	4-5	.600	6-7
October 5	.930	4-5	1.077	3-4 light haze
October 7	.914	4-5	.933	4-5
October 9	.308	12-14 very clear	.500	7-8
October 10	.673	5-6	.622	6-7
November 1	.526	7-8	.499	7-8
November 2	.984	3-4 light haze	1.034	3-4 light haze
November 5	.544	7-8	.525	7-8
November 6	.626	6-7	.500	7-8
November 8	.631	6-7	.787	4-5
November 9	.712	5-6	.905	4-5
November 26	.574	6-7	.641	6-7
November 27	.632	6-7	.641	6-7
December 9	1.126	3-4 light haze	.834	4-5

Pearson r between β_c Target 3-100 and β_c Target 4-100 = .78 $\pm$ .06

The "daylight visual range, sea miles" is taken from Tousey, R., Friedman, H., and Hulbert, E.O., Report on some Devices for Measuring Atmospheric Attenuation of Light. NRL Res. No. H-2303, 6 June 1944.

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ABSTRACTS

224. Standards For General Purpose Sun Glasses.
Dean Farnsworth,
U. S. Naval Medical Research Laboratory, Submarine Base, New London, Conn.
Report No. 2, BuMed NM 000 009, 10 September 1948, 27 pp. (0)

"Tolerance to sunlight varies widely from individual to individual. Protection of the eyesight of navy personnel requires that adequate sun glasses be available to men who suffer eyestrain due to sunlight.

"As the result of laboratory tests, field studies and a survey of the literature, the following standards have been adopted for the evaluation of sun glasses which are offered for general issue or over-the-counter purchase for use in ordinary occupations outdoors in daylight.

A.	LIGHT	Percent transmission of visible light--10%-16%. Lenses matched to within 1/5 of transmission.
B.	HEAT	Percent transmission of infrared 700-1400 mu--less than 10%.
C.	ULTRAVIOLET	Transmission of erythemal band of sunlight -- less than 10%.
D.	NEUTRALITY	Freedom from chromatic color in excitation purity -- 0% preferred, up to 25% acceptable.
E.	SIZE OF LENSES	Measured on New London Scale -- #5-#6 preferred, smaller sizes acceptable for small heads.
F.	BASE CURVE	6 base curve preferred, 4 to 9 base curve acceptable.
G.	GEOMETRIC OPTICS	Free from visible defects; not over 1/8 prism diopter; focal power not over 1/16 diopter.
H.	FRAMES	Should permit fitting of lenses to cover the visual field; without chemical reaction; non-glaring.
I.	PHYSICAL SPECIFICATIONS	As given in AN-G-22a are generally acceptable.

"It appears that the theoretical goals for the design of the best general-purpose sunglass would be the following:

1. Twelve percent transmission of visible light.
2. No transmission of infrared or ultraviolet.
3. Neutrality in color and uniform spectral transmission in the visible region.
4. Complete coverage of the field of view so as to exclude all peripheral light.
5. Freedom from optical aberration or defect.
6. No impairment by usage.

"Emphasis is laid in the discussion on five qualities which have not, on the whole, been stressed in previous standards.

1. The usefulness of fairly dense glasses (lower in transmission than are now commonly available).
2. The desirability of color neutrality.

3. The importance of heat absorption.
4. The need for full coverage of the field in view.
5. The necessity for well matched lenses.

"There is at present inadequate experimental data with which to justify narrower tolerances than those adopted, and with which to evaluate the relative importance of the various factors."

225. <u>Optical Quality Studies of Instruments of Naval Interest</u>.
U. S. Navy, Bureau of Ordnance
NavOrd Report 436, 5 April 1948, 100 pp. (C)

"During and since World War II, a number of new or improved methods have been developed for evaluating the quality of optical systems. These methods have been used to study the quality of a number of optical systems of interest to the Navy. This study involved 178 specimens of 55 different designs of visual telescopic systems. The work was performed as a part of Task C of Contract NOrd-7958 between the Bureau of Ordnance of the Navy Department and the Optical Inspection Laboratory of The Pennsylvania State College. The methods used to test the optical systems are objective in nature and yield numerical values of quality which may be related to actual performance of the optical systems under consideration. These methods utilize five different types of apparatus referred to as:

1. The Kinetic Definition Chart Apparatus
2. The Dioptometer
3. The Interferometer
4. The Contrast Rendition Apparatus
5. The Light Transmission Apparatus

"The Kinetic Definition Chart Apparatus (hereafter abbreviated to K. D. C.) is essentially a continuously variable resolving power chart in which the target contrast and the brightness level at which the observations are made can be varied at will. The K. D. C. apparatus may be used to evaluate the quality of optical systems at various field angles and under conditions closely simulating those encountered in use. Numerical values obtained using the K. D. C. apparatus are expressed in terms of a percentage, referred to as the K. D. C. efficiency. An optical system free from aberrations should have a K. D. C. efficiency of 100 percent. Those naval instruments studied were found to have axial K. D. C. efficiencies ranging from 98 to 44 per cent and values as low as 4 percent at the edge of the field. In the case of targets of different contrasts, the instruments studied had axial K. D. C. efficiencies ranging from 63 to 8 percent at a target contrast of 10 percent and from 87 to 28 percent at a target contrast of 50 percent.

"The Dioptometer is a simple telescopic system which may be used to measure the astigmatism of an optical system at various field angles. The numerical results of the dioptometer measurements are expressed in terms of diopters of astigmatism that would be presented to the eye when viewing a target through an optical instrument at any specified field angle. For those instruments studied, the astigmatism was found to range from + 1.25 to -6 diopters at the edge of the field. Some instruments were found to have astigmatism on the optical axis. This indicated a lack of conformance with the design. The values of axial astigmatism were found to range from + 0.75 to -0.50 diopters for the instruments studied.

"The Interferometer is an optical device by means of which it is possible to evaluate the quality of an optical system from the point of view of the wave (electromagnetic) theory of light. This evaluation is based on undesirable changes introduced into the wave front of light passing through an instrument under test which would result in a deterioration in quality of the image formed by that system. The interferometer data are obtained in a form referred to as interference patterns. The interference pattern provides a measure of the optical quality in terms of a quantity referred to as Interferometer Quality. The Interferometer Quality (abbreviated I. Q.) may be thought of as being the percentage of the cross-section of the optical system that is free from aberrations.

"I.Q. Measurements may be made at various field angles in a similar fashion as the K. D. C. measurements. A high grade optical system should have an I. Q. of 100 percent. The axial values for the instruments studied were found to range from 93 to 31 percent and the extra-axial values were as low as 9 percent. The Interferometer is believed to be the most rapid and accurate method available for determining the optical quality of telescopic systems of moderate dimensions.

"The Contrast Rendition apparatus is a photoelectric device which is used to measure the amount of stray light in optical systems. Stray light falls on an image formed of an object and reduces its contrast and hence its visibility. Then Contrast Rendition apparatus provides a means of comparing the contrast of the image of an object formed by an optical instrument, with the contrast of the object itself. This comparison when made on percentage basis, is referred to as the Contrast Rendition of the optical system. This is a newly recognized and yet most important property of an optical system. It is probably more important than the optical aberrations or light transmission as far as field performance of optical systems is concerned. A high grade optical instrument should have a Contrast Rendition of 100 percent. The Contrast Rendition values for the instruments studied were found to range from 98 to 2 percent for simulated field conditions.

"The Light Transmission apparatus is a photoelectric device designed to measure the transparency of an optical system under consideration. The apparatus is designed in such a way as to eliminate errors in the measurements caused by stray light and is somewhat different in design from conventional apparatus. A perfect optical system should have a light transmission of 100 percent. The light transmission values obtained for those instruments studied ranged from 77 to 40 percent.

"The numerical results of the tests using the K. D. C. apparatus, the Dioptometer, and the Interferometer have been correlated. A high degree of correlation has been found. A study of the correlation indicates that astigmatism is the principal aberration inherent in the 24 different Navy designs studied."

226. Abrasion Resistant Coating For Transparent Plastics.
Mortimer H. Nickerson,
DeBell & Richardson, Inc., Springfield, Mass.
Summary Report, Contract No. W-44-109-qm-1978, O. I. 2519
(GFM-411) 1 September 1948, 15pp. (R)

"An abrasion resistant coating has been developed which is tough, reasonably flexible, optically clear, and can conveniently be applied to transparent plastic

sheets of nearly any desired thickness and size. The coating consists of a melamine formaldehyde resin condensed in the ratio of 1:4 respectively, plasticized and toughened by the inclusion of 25% of the salt of an aliphatic diamine and an aliphatic dibasic acid, preferably hexamethylene diamine and maleic acid. Plastic sheets coated both sides with this formululose acetate butyrate and ethyl cellulose in thicknesses of 10 to 30 mils and in a sheet size of 20 by 50". The abrasion resistance is approximately 15 to 20 times as great as the uncoated material, while a 10-mil sheet of coated cellulose acetate can be bent 180 degrees over a 1/4" mandrel without crazing or cracking off of the coat."

227. Comparative Performance Of Commercial Screening Devices And Far And Near Wall Charts Utilizing The Same Test Targets.
Ellsworth B. Cook
U. S. Naval Medical Research Laboratory, Submarine Base, New London, Conn.
Progress Report No. 5, No. NM-003-011(X-493), 30 August 1948, 69pp. (0)

"An experiment was conducted with 128 subjects to compare measures obtained with three commercial visual screening devices (Ortho-Rater, Sight Screener and Telebinocular) and with photographic reproductions of their test targets for use at the 13-inch and 20-foot distances in a visual alley. It was anticipated that this experiment would yield information as to the causes of differences previously noted between measures of visual acuity obtained with commercial screening devices and by means of the clinical method of testing.

"Statistical analysis substantiated the hypothesis that an instrument-alley factor and a test target factor are present in a measure of visual acuity. It is recognized that each of these factors is complex, and a factor analysis of all the data is being conducted to learn more of the components."

228. A Factor Analysis Of Acuity And Phoria Measurements Obtained With Commercial Screening Devices And By Standard Clinical Methods.
Ellsworth B. Cook
U. S. Naval Medical Research Laboratory, Submarine Base, New London, Conn.
Progress Report No. 4, No. NM-003-011(X-493), 15 August 1948, 26pp. (0)

"Sources of test score variance found in measuring visual functions with commercial screening devices and by means of standard clinical procedures were investigated by factor analysis. They were identified as retinal resolution, lens accommodation, form (letter) perception, resistance to interference, and depth perception in the case of visual acuity and depth data, and as lateral phoria, near lateral phoria (convergence efficiency), vertical phoria, and vertical rest in the case of phoria data.

"Sources of score variance specific to one instrument of method exist in all these visual measurements, with non-pertinent factors accounting for a sizable portion of variance in all cases. Accordingly, it is emphasized that the assumption of interchangeability of either interpolation of scores or validities from one instrument or method to another is to be avoided. In establishing visual standards for military or industrial purposes, cognizance should be taken of the possible importance of the role played by any one or any combination of the factors isolated."

229. Summaries Of Completed Research Projects.
U. S. Air Force, Randolph Air Force Base, School of Aviation Medicine, Air University, Department of Opthalmology
From 1 January 1942 to 31 March 1948, 37pp., (0)

230. Visual Acuity Measurements With Three Commercial Screening Devices.
Ellsworth B. Cook
U. S. Naval Medical Research Laboratory, Submarine Base, New London, Conn.
Report No. 2, BuM&S Research Project Number X-493 (Av-263-p)
22 April 1948, 44 pp. (0)

"This report presents an evaluation of the reliability and validity of scores obtained with three commercial screening devices:

Bausch and Lomb Company Ortho-Rater
American Optical Company Sight Screener
Keystone View Company Telebinocular

"Conventional letter reading tests were selected arbitrarily as the standard against which the performance of the commercial screening devices were compared. The standard target which served as our criterion was the New London chart designed at this activity with letters constructed according to Snellen specifications but with a more even distribution of difficulty and more gradations of acuity at the critical level between 20/20 and 20/15 than occur in the commercially produced Snellen letter charts.

"128 observers were examined twice in a test-retest situation, and the comparative reliability of each of the devices was determined by computing the consistency of measurement.

"The reliability of measurement with screening devices following the procedures prescribed by the manufacturers was found to be slightly inferior to that of the New London letter chart designated as the standard target. The model of the Keystone View Company Telebinocular in current use at the time of this study proved inferior both in reliability and validity to the Ortho-Rater and Sight Screener. No choice between the other two instruments can be indicated statistically in the opinion of the writers and depends solely upon personal "intangible" preference."

231. Spectral-Transmissive Properties And Use Of Eye-Protective Glasses.
Ralph Stair
U. S. Department of Commerce, National Bureau of Standards, Washington, D. C.
Circular 741, 8 October 1948, 34 pp. (0)

"This paper contains spectral-transmissive data on most of the widely distributed brands and types of glasses employed in protecting the eyes from harmful ultraviolet, visible, or infrared radiant energy, which may be encountered in industry, in driving, or while at home or at play. The standardization of shade numbers for protective glasses used in industry, glasses for special welding operations, the use of colored glasses for night driving, and the elimination of glare in sunlight are given considerable attention."

232. Discrimination Of Small Time Intervals Between A Visual And An Auditory Signal.
J. W. Gebhard, and Halsey, R. M.
U. S. Navy, ONR, Special Devices Center
The Johns Hopkins University, Psychological Laboratory(ICR), Baltimore, Md.
Technical Report -SDC 166-I-60, 1 January 1949, 14 pp. (R)

"A display of information which presents the same objective facts to the eyes and ears would be advantageous in certain radar situations. An important problem in the successful application of such a display is the sensitivity of individuals to auditory and visual signals separated by small time intervals. To study this, a series of experiments was performed to test the ability of individuals to detect the coincidence of stimuli presented to the eyes and ears at nearly the same time. An exploratory attempt to make an audio and a video signal coincide on a repeater PPI showed that blips could not be made small enough or separated accurately enough to test the limits of discrimination. Therefore, a special apparatus simulating a PPI type of presentation was constructed to allow accurate positioning of 1/32 inch dots ("targets") anywhere on a 12 inch display. A rotating pointer ("sweep") of variable speed passed the dots coincident with a click heard in the observer's earphones.

"For the conditions tested in the experiments, one or two dots were employed and the audio signal was given at positions preceding, following, or on the dots. The task of the observer was always to judge when the click occured with respect to the visual positions.

"A study of the following conditions produced these results:

1. "Effect of two dots versus one dot. Two dots were placed on the display one degree apart at equal radii; the click was given randomly with either dot. This condition was compared with a one dot display in which the click position (a) preceded the dot by one degree, (b) followed the dot by one degree or (c) was coincident with the dot. In either condition the threshold, defined as the time interval separating the positions at which 75 percent correct judgments were obtained, was from about 10 to 20 milliseconds depending upon the observer. Ninety percent correct judgments were obtained with intervals of from 15 to 30 milliseconds.

2. "Effect of radial position of dots. Two dots separated by one degree and placed at 1.5, 2.5, and 5.0 inches on the radius gave thresholds that were the same. Seventy-five percent correct judgments were obtained with about 10 to 20 milliseconds of separation.

3. "Effect of position on circumference of the display. Two dots separated by one degree were placed five inches from the center of the display at bearing 000, 090, 180, and 270. No consistent effects of bearing position were evident in the data; the thresholds were as above.

4. "Effect of angular separation. Two dots were placed at five inches from the center of the display and separated by 1.0, 2.0 and 3.0 degrees. A slight, consistent increase in thresholds was noted for the larger separations. No explanation can be given for this finding at this time.

"Individuals varied markedly in the fineness of their ability to detect the coincidence of auditory and visual signals and did not show evidence of learning

after the first few trials. Their thresholds, as measured by the methods of this experiment, were very stable and could be readily reproduced.

"The finding that 90 percent correct judgments of coincidence can be obtained from practiced observers when the separations in time between stimuli to the eyes and the ears is as little as 15 to 45 milliseconds, indicated that the quality of this ability is adequate for certain applications to a radar type of audio-visual display. Operators would be able to associate correctly an auditory signal with a target at any commonly used rate of scan, even if the identified target was very near in bearing to another."

233. The Effect Of Certain Illuminants On Scores Made On Pseudo-Isochromatic Tests.
Dean Farnsworth, Reed, J. D. and Shilling, C. W.
U. S. Naval Medical Research Laboratory, Submarine Base, New London, Conn.
Color Vision Report No. 4, 22 November 1943, 9 pp., (O)

"The selection of pseudo-isochromatic plates and the interpretation of the scores have been decided from studies made under standard illuminants. However, color tests in the Navy are administered under a wide variety of lighting conditions. The color temperature of a number of these illuminants was measured, and two test lights were selected which represented diverse parts of the color-illuminant range: one, yellowish incandescent light, the other standard mixed daylight. An abridged set of A. O. Plates was given to a test group under these two lights.

"Variations in "natural" daylight were sufficient to account for large differences in the error scores of deuteranomalous observers.

"Change from mixed daylight to yellowish incandescent light reduced the total error scores of the deuteranomalous observers by more than half.

"Approximately half of the deuteranomalous observers in the test group passed the same test under yellowish illumination which they failed under standard white.

"Lesser to no change was found in the protanomalous scores made under the two illuminants.

Conclusions:

"Present acceptance-rejection standards are invalid when pseudo-isochromatic plates are administered under non-standard illumination.

"The administration of the plates under yellowish light-natural or incandescent -- tends to cause rejection of protanomalous and acceptance of deuteranomalous applicants."

234. Checkerboard Visual Acuity Targets: An Experimental Validation.
Forrest L. Dimmick and Rudolph, Leon M.
U. S. Naval Medical Research Laboratory, Submarine Base, New London, Conn.
Report No. 1 on BuMed Research Project NM 003 008 (X-423)
December 1948, 14 pp. (O)

"Checkerboard visual acuity targets of various sizes were examined to determine whether they contained secondary cues which could distort visual acuity measurements taken with them.

"Tests were made under constant illumination with one hundred and eleven targets, whose individual checkers subtended one minute of visual angle at a series of distances from 7.08 feet to 67.40 feet. Every target was presented at five testing distances on a $\log_2$ scale in quarter log steps, ranged about the distance at which one minute of visual angle is subtended. Three observers were used to validate each target.

"Distribution curves of correct judgments against distance were compared to the normal curve, and those targets which gave curves not of the normal type were rejected. Thus a series of valid targets (i.e., those measuring resolution primarily) was obtained. Such a series is an essential for a program of visual acuity measurements.

"In addition to validating targets, this work throws light on the relation of visual angle to testing distance: small visual acuity targets presented at short testing distances have the same acuities as large targets presented at greater distances."

235. Experimental Evaluation Of The New London Navy Lantern For Testing Color Perception.
Walter F. Grether, Connell, Shirley C. and Bjornstad, Jeanne M.
U. S. Air Force, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio
Memorandum Report, MCREXD-694-21B, 1 March 1949, 11 pp., (0)

"The purpose of this investigation was to make a laboratory evaluation of the New London Navy Lantern, as requested in a letter from the Office of the Air Surgeon, Headquarters, USAF, dated 19 March 1948.

"The New London Navy Lantern is one of the "lantern" type of color vision tests which required the examinee to name colored lights subtending small visual angles. Seventy-one normal and ten color deficient adults were tested and retested with the Navy Lantern and also with three types of Pseudo-Isochromatic Plates, two types of Anomaloscope, and a test for location of the spectral Neutral Point.

"The results showed that five (50%) of the ten color deficient subjects made perfect scores on the Navy Lantern on the first test, and three (30%) made perfect scores on the retest. Seven (10%) of the normal subjects made one or more errors on either the test or the retest with the Navy Lantern.

"The Navy Lantern was found to have several mechanical conveniences desirable in a color vision test. However, the model used in this investigation (Serial No. 120) also had a number of minor mechanical defects which should be corrected in future models.

"The following conclusions concerning the New London Navy Lantern appear justified by the results of this investigation:

a. The lantern is a relatively insensitive device for detection of color deficiency, and will pass many individuals with rather marked color deficiency as indicated by other tests. This finding is in general agreement

with the purpose for which the test was designed (Farnsworth, D., in Minutes and Proceedings of the Armed Forces-NRC Vision Committee, 27-28 May 1948, Page 68b).

b. The nine trials, as provided by the test, if administered only once, do not appear to give adequate test-retest reliability for detection of persons with mild color deficiency.

c. Persons with normal color vision may be falsely diagnosed as color blind unless the lantern is administered by a skillful and cautious operator or another test is used to check the diagnosis.

d. The test is excellently designed mechanically for the convenience of the operator. There are, however, a number of minor defects which could be corrected easily in future models."

236. Estimation Of Airplane Speed And Angle Of Approach.
William C. Biel, and Brown, Guy E., Jr.
U. S. Navy, ONR, Denison University, Granville, Ohio
Final Report, Contract N6ori-189, Project Number NR-143-151, March 1949, 131 pp. (O)

"The purpose of this study was to determine (1) the accuracy with which observers could estimate airplane speed, (2) the changes in speed estimates resulting from observers being trained in speed estimation by one method, and (3) the accuracy with which observers could estimate the time at which 30° and 45° angles-of-approach is defined as the angle formed by the intersection of (a) the line-of-sight to the tail of the target and (b) the course line being flown by the airplane.

"Twenty commissioned Army officers recorded their individual estimations of the speed and angle of approach of airplanes being flown on straight-and-level courses which varied in speed, direction, altitude and "minimum slant range" on different approaches. Airplanes used were the B-26, AT-11, B-25, PQ-14, P-47, and P-63.

"A definite relationship was found between the speed of the airplanes and the direction and size of the error made by the observers in estimating these speeds. Within the range of speeds used, low speeds tended to be overestimated and high speeds to be underestimated. The higher the speed the larger the underestimation even though the observers' actual estimates increased with increases in speed."

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